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Water Quality of Okanagan, Kalamalka, and Wood Lakes

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WATER QUALITY OF OKANAGAN, KALAMALKA, AND WOOD LAKES

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WATER QUALITY OF OKANAGAN, KALAMALKA, AND WOOD LAKES

ABSTRACT

In this report lake water quality is reviewed as part of the Okanagan Sub-Regional planning process. Most of the data were collected by Waste Management during the period 1970 to 1988 for Okanagan, Kalamalka and Wood Lakes. Most parts of Okanagan Lake and Kalamalka Lake are oligotrophic whereas Wood Lake is mildly eutrophic. Armstrong Arm of Okanagan Lake approaches mesotrophy because it is shallow and has a high nutrient load from Deep Creek and littoral lake sediments. There were differences in phosphorus levels among the lakes and among locations within lakes. In general, those locations which were high in phosphorus were also high in other measures of eutrophication such as nitrogen, phytoplankton and zooplankton.

All of the lakes showed trends in quality during the period of observations. Water quality is deteriorating in Kalamalka and Okanagan Lake but improving in Wood Lake. The deterioration of Okanagan Lake is very slow and has occurred over the last century whereas in Kalamalka Lake the deterioration is more rapid and has been especially evident during the last 2 decades. In Wood Lake, the improved water quality has been rapid and increasingly apparent for the last decade.

Spring phosphorus has increased in Kalamalka Lake but has decreased in Wood Lake. In Okanagan Lake, phosphorus levels have fallen when nutrients from sewage treatment plants were reduced at Vernon and Kelowna. All of the lakes have increased in dissolved minerals over the past few decades. Although rainfall in the Okanagan is not particularly acidic, several water quality measures have shifted in the direction to be expected from titration by rainfall on the acidic side of neutral.

On the basis of volume, most lake water met quality objectives established in 1985. Okanagan and Kalamalka Lake quality generally met their objectives whereas quality of Wood Lake and Armstrong Arm did not.

PREFACE

The objective of the Waste Management Program is to preserve the quality of the water environment of British Columbia at or above acceptable levels by managing the discharge of pollutants. The purpose of this report is to present information on lake water quality. The report wae requested in order to provide technical information for the Okanagan Sub-Regional Plan.

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INTRODUCTION

Lake water quality information is important for planning purposes in the Okanagan. The information in this report focuses on nutrients and other aspects of water quality relevant to changes induced by man. The report describes the existing quality, trends in quality, and the objectives that have been set for lake water quality.

The period of time that the report covers is mainly 1970 to 1988. Although some limnological observations were made in 1940, most of the systematic sampling and observation began with the Okanagan Basin studies starting in 1970. Some of the data summarized were actually obtained by other workers either during the Okanagan Basin Study or by those which followed it, such as the Kalamalka-Wood Lake Basin Study and the Okanagan Basin Implementation Agreement Study. For the most part the information was collected by employees of Waste Management Branch which was formerly the Pollution Control Branch.

The information was collected and put together in this report as part of the Okanagan Sub-Regional Plan for the Ministry of Environment. Information on lake quality is important so that current water quality status can be assessed and put into perspective. Equally important are descriptions of trends in water quality which have occurred. The trends show the extent of changes in lake quality probably induced by activities of man. Moreover, such knowledge permits planning for Waste Management which will protect and maintain existing water quality which is still satisfactory and reverse undesirable trends in water quality where such trends exist.

Figure 1 shows the location of wastewater outfalls into the lakes or tributary streams. Details about the wastes are given in Tables 1 and 2. At present, the largest infusion of phosphorus in the lakes comes from City of Kelowna; however, the phosphorus load from the City of Armstrong is almost as great. It is expected that Armstrong wastewater will be upgraded, although such an upgrade has been expected for more than a decade and still has yet to occur. Table 2 shows that the amounts of phosphorus discharged from various sources has changed considerably through the years. Additional details sketching changes can be found in Anonymous (1982) and Forty (1989). In addition to outfalls, there are various small discharges to groundwater scattered about the Okanagan. Summaries of such loadings can be obtained in Anonymous (1982).

Figure 1 also shows where the Okanagan lakes were sampled. This study encompasses three large lakes: Okanagan, Kalamalka and Wood. It does not include water quality of headwater lakes to these main valley lakes. Limnological observations for the sites shown in Figure 1 are presented in the following sections of this report.

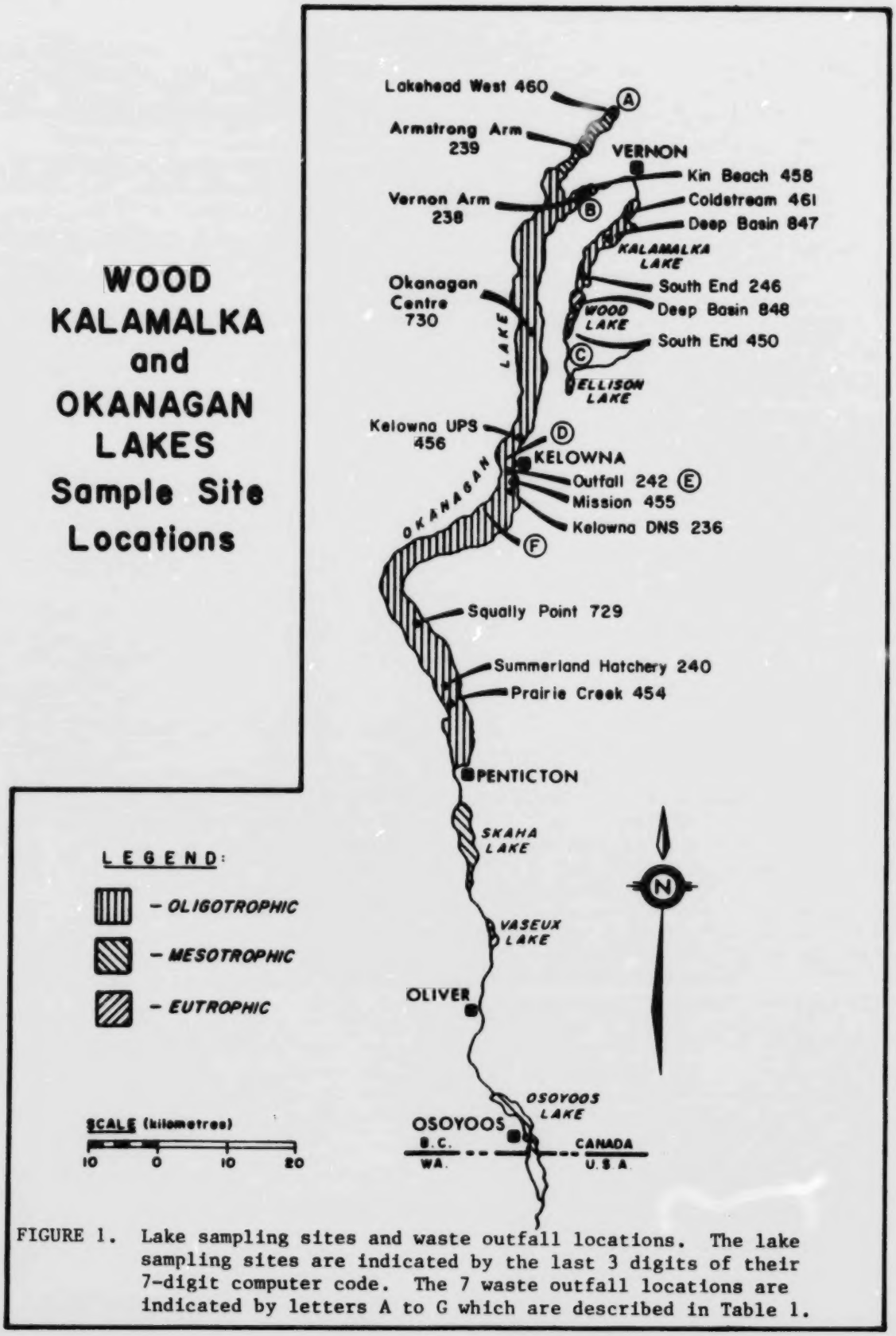


FIGURE 1. Lake sampling sites and waste outfall locations. The lake sampling sites are indicated by the last 3 digits of their 7-digit computer code. The 7 waste outfall locations are indicated by letters A to G which are described in Table 1.

TABLE 1

Description of waste discharges into Okanagan Lakes or streams tributary to the lakes. The locations of sources are shown on Figure 1.

CODE	SOURCE/ LOCATION	DESCRIPTION
A	Armstrong STP	Municipal wastewater from a secondary lagoon discharged into Deep Creek.
B	Vernon STP	Municipal wastewater from trickling filter discharged to Deep Creek until August 1977. Two emergency releases of wastewater in spring of 1984 and 1985.
C	Hiram Walker	Water used to cool the still at Hiram Walker is pumped from Okanagan Lake and released into Vernon Creek upstream of Ellison and Wood Lakes. The only waste in the discharge is heat.
D	Brandts Creek	Trade Waste Treatment Plant began operation and discharged to Brandts Creek in 1973 replacing untreated waste discharges from a cannery and winery. It is an activated sludge system of secondary treatment about 1 km from Okanagan Lake. It was secondary until 1987 when it became tertiary.
E	Kelowna STP	Municipal wastewater from activated sludge treatment system which was upgraded from secondary to tertiary (Bardenpho) in 1983.
F	Westbank STP	Municipal wastewater from secondary lagoons which discharged to Westbank Creek about 1 km from Okanagan Lake until December 1989 when tertiary treatment and a lake outfall began.
G	Trout Hatchery	Organic waste given primary treatment until about 1976 when slightly improved works were installed and better tank cleaning instituted.

TABLE 2

Phosphorus loads (kg/year) to Okanagan Lake from discharge sources 1970 to 1988. The estimates were rounded off from those given in one of three sources (Anon. 1974; Anon. 1982; or Forty 1989).

SOURCE	1970	1980	1988
Armstrong STP	1900	2400	3000
Vernon STP	16100	0	0*
Brandts Creek	170	1000	170
Kelowna STP	18500	14000	3100
Westbank STP	725	1300	1000
Trout Hatchery	170	200	270

* Wastewater releases in 1984 and 1985 were 350 and 220 kg, respectively.

METHODS

Water samples were collected, mainly using a Van Dorn water bottle. At each location sampled, water was collected from different depths in the lake. Some of the results are for discrete depths; more often, however, the data were for composites of three samples from the epilimnion or hypolimnion. The epilimnion is the upper layer of the lake, and the hypolimnion is the lower layer of the lake. These layers are created as the lake warms because the density of water decreases in the epilimnion. Three samples from each depth were composited even in the springtime when the lake was isothermal and the two layers of different density did not exist.

Profiles of temperature and oxygen were measured for each site using a Y.S.I. meter. Temperature and oxygen were confirmed independently with hand thermometers and the Hach variation of the Winkler method. Usually the deepest water sample in a lake was titrated to determine that the electronic meter gave reliable results.

Phytoplankton samples were collected with a Van Dorn at the epilimnion depths which were sampled. Phytoplankton was always measured as chlorophyll *a*. Chlorophyll *a* determinations, like all chemical analyses, were performed by the B.C. Ministry of Environment Laboratory, which used standard methods. Zooplankton samples were collected by hauling a plankton net vertically, usually from 45 m to the surface. This net was 50 cm in diameter and had mesh openings of 150 microns.

RESULTS

A. EXISTING QUALITY

Water quality in the Okanagan Lakes, has changed through time. As in lakes in general, most of the changes occurred because of nutrient enrichment as nutrients were transported from land and air into the water. This transport can be greatly accelerated by activities of man.

As nutrient concentrations increase, other characteristics of lakes also change. When lakes become richer in such nutrients as phosphorus and nitrogen, the phytoplankton density per unit volume of water increases. Consequently the lakes become less clear, often developing a greenish hue instead of a clear blue colour. This process can be greatly accelerated by activities of man such as: erosion, discharge of nutrient-rich wastes, runoff from agriculture and logging. The most important of the nutrients is phosphorus because it is the nutrient in shortest supply in Okanagan lakes, as in most lakes.

The process of lake enrichment is called eutrophication. Lakes which are very rich in nutrients are classified eutrophic; those which are rather poor in nutrients are oligotrophic (Table 3). Lakes which fall in between these two categories are mesotrophic. These categories imply a whole host of characteristics apart from just nutrient concentration.

TABLE 3

Typical ranges of phytoplankton and nutrient parameters for lakes of different trophic status (Nordin 1985).

Trophic Status	primary production ($mgC/m^2/day$) growing season mean	chlorophyll $\underline{a}$ (ug/L) growing season mean	total P (ug/L) at spring overturn	total N (ug/L) at spring overturn	Secchi disc (m) growing season mean	Hypolimnetic oxygen depletion ($mg\ O_2/m^2/day$)
Oligotrophic	50-300	0-2	1-10	<100	>6	<250
Mesotrophic	250-1000	2-5	10-20	100-500	3-6	
Eutrophic	>1000	>5	>20	500-1000	<3	>500

Oligotrophic lakes have a completely different flora and fauna from eutrophic lakes. Oligotrophic lakes have a high concentration of oxygen in their deep waters throughout the year whereas eutrophic lakes are frequently devoid of oxygen in the hypolimnion (lower layer) during the summer. In the winter, eutrophic lakes which freeze can use up oxygen that is stored in the water. The low-oxygen water over the sediment in eutrophic lakes can release phosphorus to re-enter the water column from the sediment. In oligotrophic lakes, nearly all phosphorus remains locked up in sediments and does not enter into the phosphorus cycle of the lake water itself. Some characteristics of lakes in different trophic categories are given in Table 3 which was reproduced from a report by Nordin (1985).

The three lakes in the plan area were classified as to trophic category in the early 1970's by the Okanagan Basin Study and again in the early 1980's by the Okanagan Basin Implementation Program. In both studies, the main bodies of Okanagan and Kalamalka Lakes were classified as oligotrophic (Figure 2). The authors of the Okanagan Basin Study (Anon. 1974b), concluded that Kalamalka was the most oligotrophic of the lakes and described it as ultra-oligotrophic. In the Okanagan Basin Implementation work Wood Lake was classified as mildly eutrophic whereas the Okanagan Basin Study placed it in the eutrophic category.

The lakes are not homogeneous bodies of water. Some locations are richer in nutrients, phytoplankton and zooplankton than others. This is particularly true of Okanagan Lake but to some extent it is also true of Kalamalka Lake. Wood Lake is much more homogeneous than the other two. Each lake is described in greater detail in the following sections:

1. Okanagan Lake

   The main body of Okanagan Lake is oligotrophic (Anon 1974b, 1982). There are some shallow areas in Vernon Arm and Armstrong Arm which approach mesotrophy (Anon. 1974b). Except for nitrogen, the characteristics observed in Okanagan Lake are typical of oligotrophic lakes (Table 3). This is particularly true of Armstrong Arm which is a rather shallow and long finger of Okanagan Lake (Figure 2). Because of its shallow depth, the volume of water in the hypolimnion is small relative to the surface area. Because of this, oxygen depletion is commonly observed there. As phytoplankton dies and decomposes, oxygen is consumed and the concentration decreases. The hypolimnion has never been observed to be anoxic but oxygen concentrations have been much lower than elsewhere in Okanagan Lake. The shallow water in Armstrong Arm warms to a much greater extent than most other locations in Okanagan Lake.

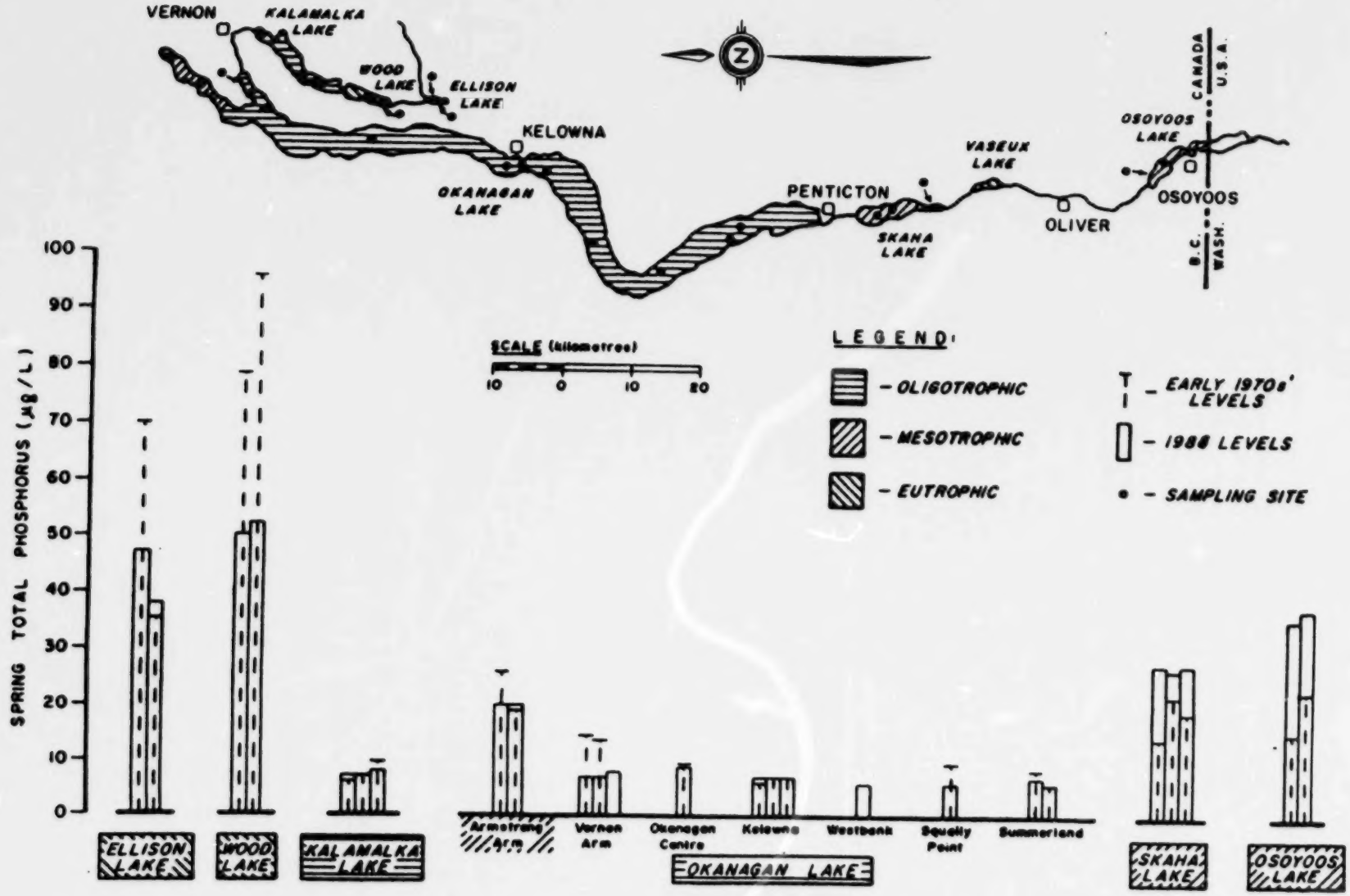


FIGURE 2. Trophic status and spring phosphorus concentration of Okanagan Lakes. Each sampling site is indicated by a dot and a histogram showing spring phosphorus level. The histograms are arranged from the most upstream site on the left to the most downstream site on the right.

Figure 2 shows that phosphorus concentrations are higher in Armstrong Arm than in the rest of Okanagan Lake. Deep Creek at the head of Armstrong Arm provides a rich source of phosphorus. Because the Arm is shallow, more phosphorus per unit area is returned from the sediments to the water than elsewhere in the lake. The theoretical flushing time for Armstrong Arm is only about 2 to 10 years, whereas for the main body of the lake the flushing time is 53 - 60 years (Anon. 1985). Zooplankton and phytoplankton are elevated relative to most other parts of Okanagan Lake (Table 4).

Another area of high nutrient concentration was Vernon Arm. Like Armstrong Arm, Vernon Arm is a shallow body of water with Vernon Creek flowing into it. Although nutrient concentrations in Vernon Creek are much lower than in Deep Creek, they are much higher than in Okanagan Lake, so elevate the concentration in Vernon Arm. Flushing time in Vernon Arm ranges from a few days near Vernon Creek to 2 years at the junction of Vernon Arm with the main body of Okanagan Lake.

Historically, Vernon Arm had even higher nutrient concentrations when the City of Vernon discharged its wastewater to Vernon Creek (Bryan 1987). Phosphorus and phytoplankton concentrations in Vernon Arm still tend to be slightly higher than in the deeper parts of Okanagan Lake (Figure 3, Table 4). Phytoplankton has decreased in Vernon Arm because the discharge to Vernon Creek was stopped when the spray irrigation system was completed (Jensen, MS 1981). So the average concentration in Table 4 is biased upwards by the higher levels for the 3 years when wastewater was still in the Arm.

Because of the heterogeneity in Okanagan Lake water, spring phosphorus concentrations differ in various parts of the lake (Figure 2). Concentrations of phosphorus are generally low in deep parts of Okanagan Lake such as: Okanagan Centre, Kelowna, Squally Point and Prairie Creek. Stations in shallow areas have higher phosphorus levels due to runoff from the shore and return from the sediments. Deep locations have phosphorus levels consistent with those for oligotrophic lakes (Table 3).

Okanagan Lake is lower in macronutrients (nitrogen, phosphorus, and potassium), than Kalamalka or Wood Lakes (Table 5). It is also lower in phytoplankton and organic carbon; as a consequence, it is clearer than the others. Okanagan Lake has lower conductivity, and most dissolved material. Not being a marl lake, it is lower in calcium and sulphate than Kalamalka.

TABLE 4

Summary of trends* and average standing crop of plankton in lakes of the Okanagan Region. Phytoplankton was sampled in late summer or early autumn (August 15 to October 15) and measured as chlorophyll a. Zooplankton was sampled in late winter or early spring (Feb. 15 - May 15), and total volume of settled zooplankton measured. For a particular site, the annual variation in sampling date is usually less than 14 days.

		Phytoplankton		Zooplankton	
LAKE	STATION	Trend*	Average (ug/L)	Trend*	Average (ml)
Okanagan	South Prairie Creek	0	0.8	0	2.9
	Opp. Fish Hatchery	0	1.0		
	South Squally Point	0	0.9	-	6.2
	DNS Kelowna STP (Deep)	0	0.9	0	6.5
	Opp. Kelowna STP Outfall	0	1.0		
	UPS Kelowna STP	0	1.0	0	4.4
	North Okanagan Centre	0	0.9	-	7.2
	Central Vernon Arm	-	1.4	0	4.7
	Kin Beach West	-	1.7		
	Central Armstrong Arm	0	1.6	-	11.4
	Lakehead West	0	1.8	-	
Kalamalka	S. Coldstream Creek	+	0.8	0	7.0
	Rattlesnake Pt./Deep Basin	0	1.0	0	4.5
	South End	+	1.0	0	4.4
Wood	West Vernon Creek	-	5.5	0	15.0
	Deep Basin	-	4.7	0	25.0

* TREND apparent for the entire data set for a particular site. The year of first observation varied from 1970-1975 for different sites, and for some sites there were years when no samples were taken. These trends were judged by inspection without the use of statistics.

\+ Slight Increase
\- Slight Decrease
0 No trend

TABLE 5

Comparison of average values of water quality parameters for Wood, Kalamalka, and the main body of Okanagan Lake which excludes both Armstrong and Vernon Arms. The overall mean for each parameter is characterized according to whether it is different by at least 2 standard errors (i.e. $p < .05$). When there were significant differences among the lakes, they are listed as being low(est), intermediate, or high(est). The data set analyzed includes all values recorded to 1988, and the actual data are given in the Appendix.

PARAMETER	MAIN BODY OKANAGAN LAKE	KALAMALKA LAKE	WOOD LAKE
Biological:			
Carbon, total organic	low	intermediate	high
Chlorophyll A	low	low	high
Coliform, fecal		No Differences	
Macronutrients:			
Nitrogen, total	low	low	high
Nitrogen, organic	low	intermediate	high
Nitrogen, ammonia	low	low	high
Nitrate and Nitrite	low	low	high
Phosphorus, total	low	low	high
Phosphorus, dissolved	low	low	high
Potassium	low	high	intermediate
General ions:			
Acidity		No Differences	
Alkalinity, phen.		No Differences	
Alkalinity, total	low	high	intermediate
pH	low	high	intermediate
Boron, dissolved		Insufficient Data	
Calcium, total	intermediate	high	low
Calcium, dissolved	intermediate	high	low
Magnesium, total	low	high	intermediate
Magnesium, dissolved	low	high	intermediate
Hardness, dissolved	low	high	intermediate
Chloride	low	intermediate	high
Fluoride	low	high	few data
Residue, total	low	high	intermediate
Residue, filterable	low	high	intermediate
Silica	intermediate	high	low
Sodium	low	high	high
Sulphate, dissolved	intermediate	high	low
Physical:			
Carbon, inorganic	low	high	high
Colour		No Differences	
Oxygen (hypolimion)	high	high	low
Secchi depth	high	intermediate	low
Specific conductance	low	high	intermediate
Turbidity	low	low	high

2. Kalamalka Lake

The main body of Kalamalka Lake is oligotrophic (Anon. 1974b, 1982). As in Okanagan Lake nitrogen levels are higher than normal for Oligotrophic lakes whereas other characteristics are normal. Unlike Okanagan Lake, Kalamalka Lake is a marl lake. Calcium carbonate precipitates in the summer to form marl on the bottom of Kalamalka Lake in shallow areas. The high calcium and sulphate concentrations in Kalamalka Lake (Table 5) allow such marl precipitation to occur. As marl precipitates, it may bind and remove some of the phosphorus from the water column of Kalamalka Lake. Some of this phosphorus re-dissolves at other seasons of the year, but the phosphorus scrubbing may assist in maintaining the low phosphorus character of Kalamalka Lake.

Kalamalka Lake is not entirely homogeneous. The south end of the lake appears to have a higher phosphorus concentration than the middle. The highest load of phosphorus entering the lake comes from Coldstream Creek (Anon. 1974a). To some extent the water quality of Kalamalka Lake in the bay of Coldstream Creek differs from that in the rest of the lake, but phosphorus levels have usually been lower than at the south end despite the higher loading. The present theoretical flushing time of Kalamalka Lake is 37 to 45 years; whereas before Hiram Walker started discharging cooling water through the lake, the theoretical flushing time was 53 to 65 years (Anon. 1985).

The spring phosphorus concentrations in Kalamalka Lake increased in the late 1970's reaching a maximum about 1984. Since that time, the spring levels have decreased somewhat. The present nutrient concentrations are similar to levels in early 1980's when the Okanagan Basin Implementation assessment was made. Most phosphorus concentrations for Kalamalka Lake are consistent with those for oligotrophic lakes (Table 3). Table 4 shows the levels of phytoplankton and zooplankton in Kalamalka Lake are similar to those of Okanagan Lake's main body (Okanagan Centre, Kelowna, Squally Point, and Prairie Creek). Plankton levels in Armstrong Arm and Wood Lake are higher than in Kalamalka Lake.

Kalamalka Lake has nutrient concentrations similar to Okanagan, although organic nitrogen and potassium are significantly greater (Table 5). Most dissolved nutrients occur in greater abundance in Kalamalka Lake than in Okanagan or Wood. Over the period for the entire data set, Kalamalka Lake has had greater Secchi disc readings than Wood Lake but less than Okanagan Lake. In recent years, Wood Lake has become clearer than Kalamalka.

3. Wood Lake

Wood Lake is a much smaller and shallower lake than Okanagan Lake or Kalamalka Lake. Spring phosphorus levels are higher than for the other lakes in the Okanagan Basin (Figure 2). The concentrations are characteristic of eutrophic lakes (Table 3). Because the volume of water in the hypolimnion is small relative to its surface area, there is considerable oxygen depletion in the summer. As a result, there is a net transfer of phosphorus from the sediment into the water column. Consequently Wood Lake maintains its eutrophic status.

The spring phosphorus concentration in the lake has been decreasing for the past decade (Figure 2). Some of this decrease is attributable to low phosphorus water from Okanagan Lake being pumped through the cooling system at Hiram Walker Distillery. This water flows into Wood Lake via Ellison Lake and Vernon Creek. Being low in phosphorus, it decreases the phosphorus concentration of Wood Lake. However, this additional volume of water displaces high phosphorus water from Wood Lake into Kalamalka Lake. Because of the reduced phosphorus concentrations, Wood Lake was eutrophic in the early 1970's, but only mildly eutrophic by the late 1970's (Anon. 1974b, 1982).

As a result of the decreased phosphorus, water clarity has increased and phytoplankton biomass decreased (Table 3). Despite the decrease, Wood Lake still has phosphorus levels as high as any of the Okanagan Lakes (Figure 2). As a result, the levels of phytoplankton and zooplankton in Wood Lake are also very high (Table 4).

Wood Lake is lower in potassium than Kalamalka but higher than either Kalamalka or Okanagan in all other forms of macronutrients measured (Table 5). Wood Lake is also higher in phytoplankton and organic carbon than either Kalamalka or Okanagan and, on average, less clear. Most measures of dissolved solids are higher than Okanagan but lower than Kalamalka Lake.

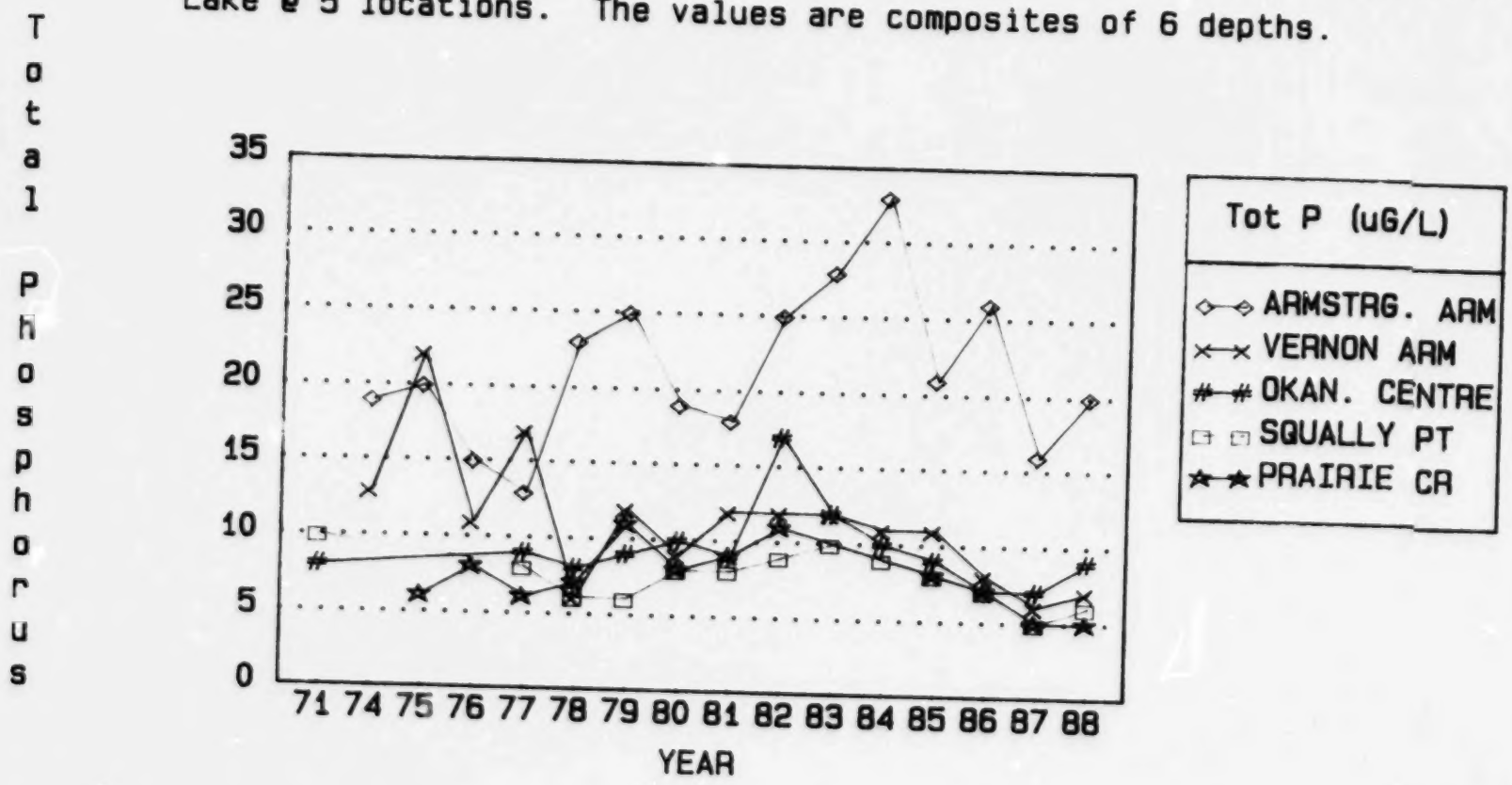
B. TRENDS IN QUALITY

1. Okanagan Lake - Phosphorus

Figure 3 shows spring phosphorus concentrations at a number of sites in Okanagan Lake. All of these sites are in deep water of the lake, meaning that each stratifies into hypolimnion and epilimnion in the summer. Figure 3 shows that both Armstrong Arm and Vernon Arm were aberrant. Armstrong Arm has consistently higher phosphorus levels than any other site in the lake.

FIGURE 3. SPRING TOTAL P IN OKANAGAN

Lake @ 5 locations. The values are composites of 6 depths.



The spring concentrations in Vernon Arm were high until 1977 but dropped after that. In August 1977 the sewage outfall was removed from Vernon Creek and spray irrigation began on a full scale basis. Pilot scale irrigation had used about 40 to 50% of the wastewater during the summers from about 1971 to 1977. Regression analysis showed that Vernon Arm had a statistically significant overall decrease in phosphorus concentration (Table 6). The levels and fluctuations in total phosphorus were similar to three other sites after 1977 (Figure 3).

Armstrong Arm phosphorus concentrations fluctuated more than the rest of the sites shown by Figure 3. At the Armstrong Arm site there was often dissolved oxygen depletion both in the autumn and spring. This indicates that phosphorus could move out of the sediments and into the water column elevating the concentrations. For the Armstrong Arm data, there is no strong trend, and there was considerable variation between years.

The other sites usually fluctuated together. Okanagan Centre, Squally Point, Prairie Creek, and Vernon Arm (after 1977) usually increased or decreased in the same year. With only a few exceptions, there was less variability among the sites than among the years. Table 6 shows that there was a statistically significant drop in total phosphorus at both sites in Vernon Arm. These are the only trends in total phosphorus data for Okanagan Lake which are both statistically significant and biologically meaningful.

Figure 4 shows the phosphorus data for sites around Kelowna. Two of the sites are in shallow water, the Outfall Site and the Mission Site. The other two sites are in deep water, where there is both an epilimnion and hypolimnion. Although the sites are designated upstream and downstream of Kelowna, there is no obvious current and the net movement of water does not occur as flow in a river although the downstream site is nearer the outlet. Between these two sites, there is no consistently higher phosphorus concentration downstream of Kelowna's outfall. This indicates that in deep water, the outfall does not have a marked impact on spring phosphorus concentration.

Between the shallow sites, the Outfall Site was considerably higher in phosphorus concentration than the Mission Site (control) until 1983. The Control Site was in the bay near the mouth of Mission Creek and south of the outfall pipe from the sewage treatment plant. In 1983 the new Bardenpho sewage treatment system for City of Kelowna began operation, decreasing the annual phosphorus loading. In years 1984 to 1988, the spring phosphorus concentration at the outfall site was considerably lower than the concentration at that site before 1983. Moreover, the values for the Outfall and Control Sites were similar after 1983.

TABLE 6

Trends* in lake quality based on spring nutrient data to 1988 for the Waste Management Monitoring Program. The stations are arranged in sequence from downstream to upstream. Total phosphorus and total nitrogen trends were tested for statistical significance using least squares regression. Dissolved P and N were not tested for statistical significance. N:P ratio show the percentage of dates when total N by weight to total P (P = 1) ratio fell into one of three categories.

LAKE	STATION	SPRING NUTRIENTS				N:P RATIO		
		TOTAL P	DIS-SOLVED P	TOTAL N	NO3+NO2	>15	6-14	<5
Okanagan								
	South Prairie Creek	0	0	0	+	100%	0	0
	Opp. Fish Hatchery	0	0	0	+	100%	0	0
	South Squally Point	0	0	0	0	100%	0	0
	DNS Kelowna STP (Deep)	0	0	--	+	97%	3%	0
	Opp. Kelowna STP Outfall	-	0	-	+	88%	12%	0
	UPS Kelowna STP	++	+	-	+	96%	4%	0
	North Okanagan Centre	0	+	0	0	96%	4%	0
	Central Vernon Arm	--	-	-	0	86%	14%	0
	Kin Beach West	--	-	0	0	77%	23%	0
	Central Armstrong Arm	+	0	--	0	29%	71%	0
	Lakehead West	0	0	-	0	14%	86%	0
Kalamalka								
	S. Coldstream Creek	+	+	0	+	100%	0%	0
	Rattlesnake Pt./Deep Basin	++	+	+	+	93%	7%	0
	South End	++	0	+	+	97%	3%	0
Wood								
	West Vernon Creek	--	+	--	0	3%	97%	0
	Deep Basin	--	+	--	+	3%	97%	0

*TREND over entire time period of measurement for each site. The first observation varied from 1970-1975 for different sites, and for some sites, there were years when no samples were taken.

+ Slight Increase
++ Significant Increase ($p<0.05$)
- Slight Decrease
-- Significant Decrease ($p<0.05$)
0 No trend

FIGURE 4. SPRING TOTAL P IN OKANAGAN L

near Kelowna's STP outfall. Composites of 3 or 6 depths.

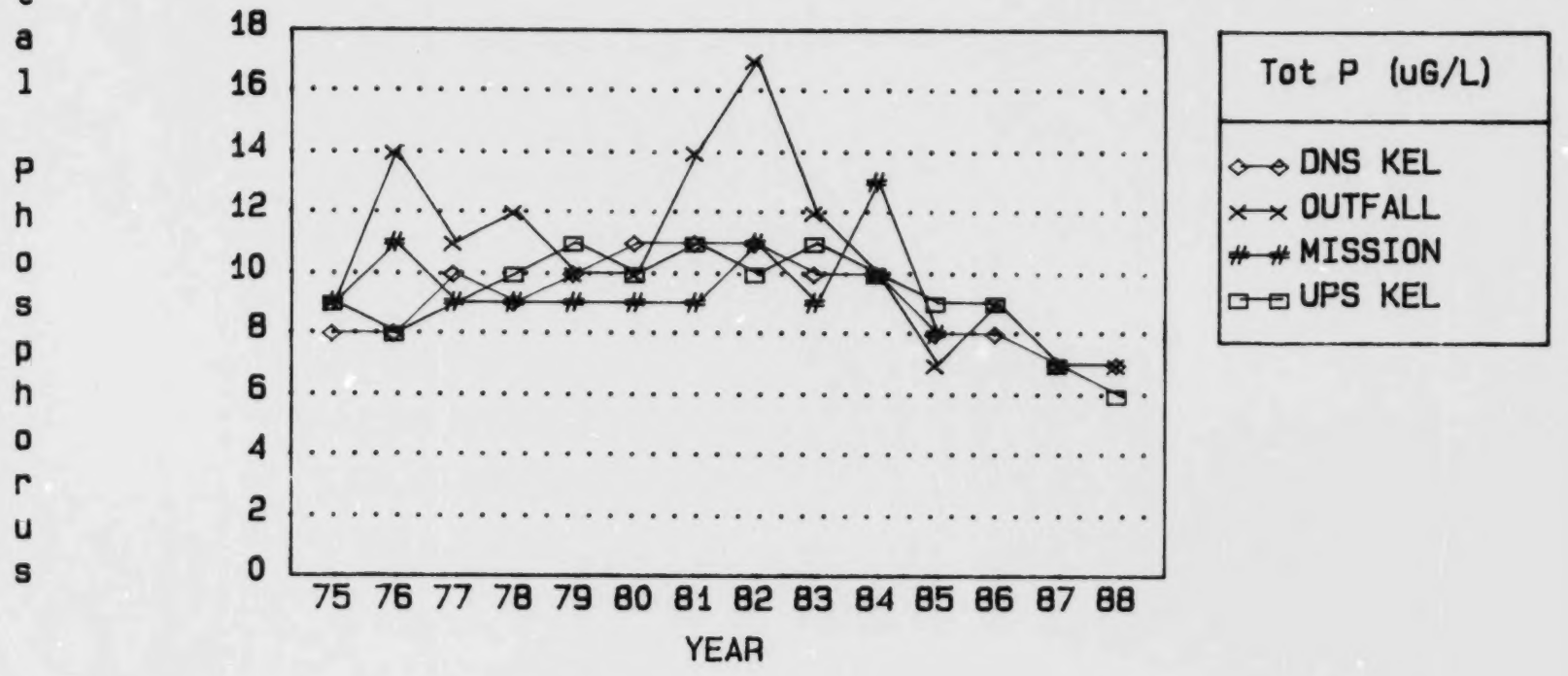


Figure 5 shows phosphorus concentrations at four shallow sites in Okanagan Lake. The depth to bottom at these sites ranged from 6 to 11 metres and all were near shore. There was no hypolimnion at any of these sites. All had phosphorus concentrations which were consistently higher than offshore sites in deep water. This is probably because runoff from land affects these sites as does the phosphorus which returns to the water column from the sediments. Of all of the sites shown, the Lakehead Site in Armstrong Arm had phosphorus concentrations which were consistently the highest.

The Vernon Arm site at Kin Beach was high in phosphorus until 1977 when it diminished and remained similar to the other 3 sites after that. The Lakehead Site is close to the mouth of Deep Creek which carries a high nutrient load. Deep Creek receives nutrients from agricultural sources and from Armstrong Sewage Treatment Plant.

Nitrogen

Figure 6 shows total nitrogen concentrations in Okanagan Lake for several sites in deep water. In several ways the patterns in nitrogen shown in Figure 6 are similar to patterns for spring phosphorus levels at these sites. Armstrong Arm was usually higher in nitrogen than the other sites. Vernon Arm had high nitrogen levels until 1977 when the Vernon Outfall was removed but remained low and comparable to the other three sites thereafter. Figure 6 suggests that there may be less synchrony in annual variation among the sites for total nitrogen than for total phosphorus. Only for Armstrong Arm was there a significant trend (downward) in nitrogen concentration across the whole data set (Table 6).

Figure 7 shows nitrogen concentrations around Kelowna. As with total phosphorus there was not always an increase in nitrogen at the deep site downstream of Kelowna. However, there was a consistent increase between the Outfall and Mission Sites. The Outfall Site had lower nitrogen concentrations after the Bardenpho came into operation in 1983. The Kelowna Bardenpho plant removes both nitrogen and phosphorus from the wastewater. Until 1983 the level was higher than the Control Site of Mission; whereas after 1983, both sites were similar in nitrogen concentration and the Outfall Site had much lower concentrations than before the Bardenpho plant was operational.

Figure 8 shows nitrogen concentrations for shallow sites in Okanagan Lake. Unlike for phosphorus, nitrogen levels at the shallow sites were quite similar to levels at the deep sites. Of all the shallow sites, the Lakehead Site in Armstrong Arm had the highest nitrogen concentrations. The Vernon Arm Site (Kin Beach) and the Kelowna Outfall Site both dropped in nitrogen concentration after the drop in respective nitrogen loads from the sewage treatment plants.

FIGURE 5. Spring total P in Okanagan L

@ 4 sites in shallow (6-11 m) water. Values 3-depth comp.

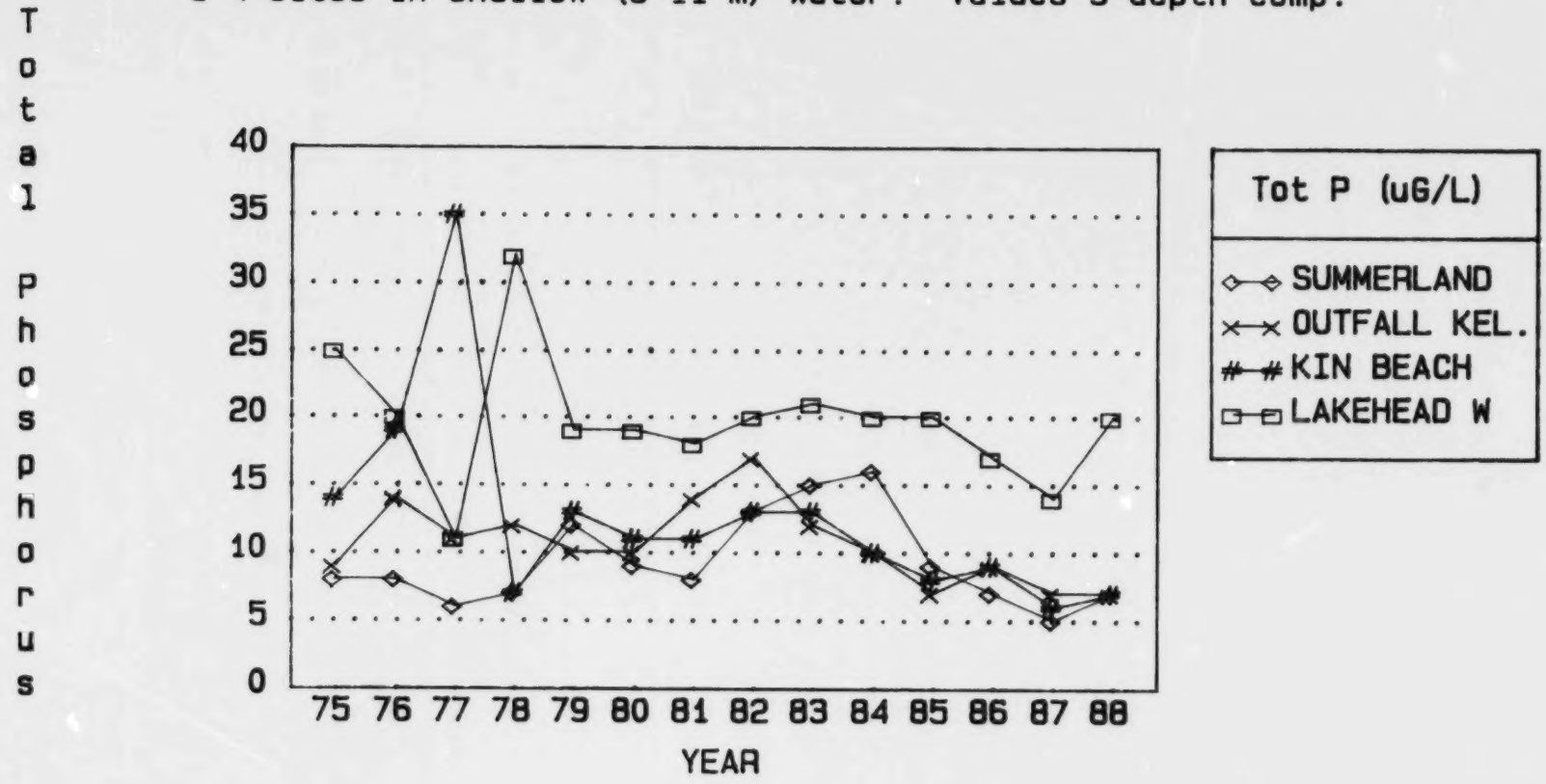


FIGURE 6. Spring total N in Okanagan L

@ 5 locations. The values are composites of 6 depths.

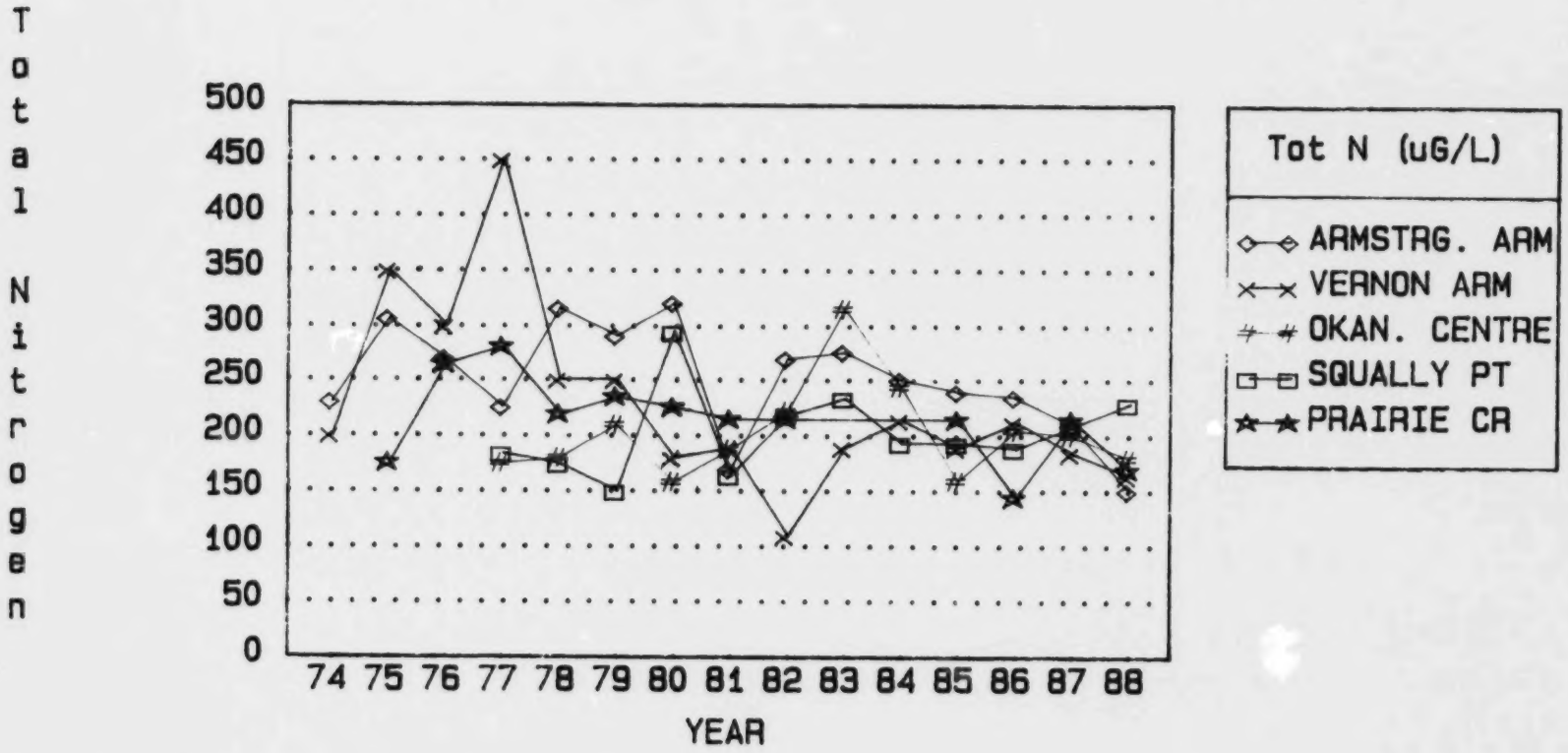


FIGURE 7. Spring Total N in Okanagan

Lake near Kelowna's STP outfall. Composites of 3 or 6 depths

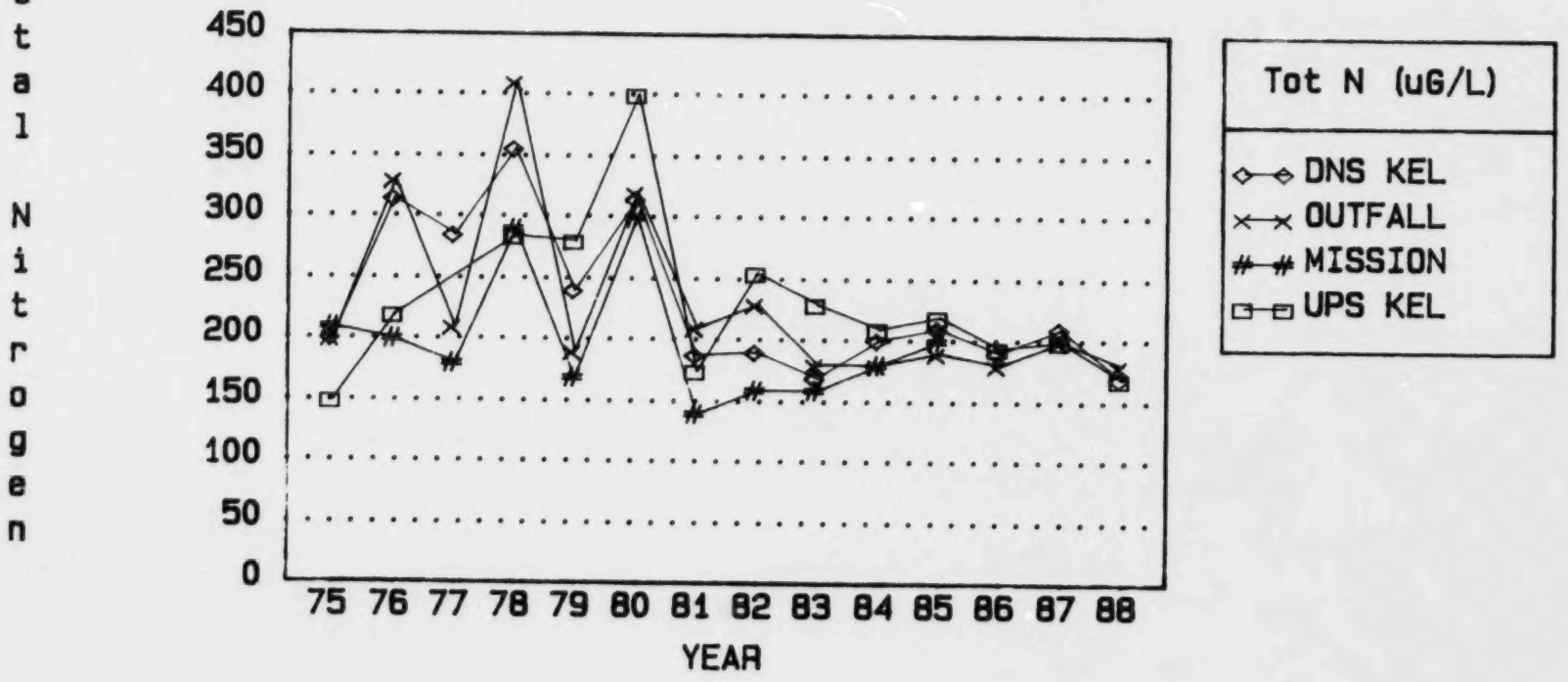
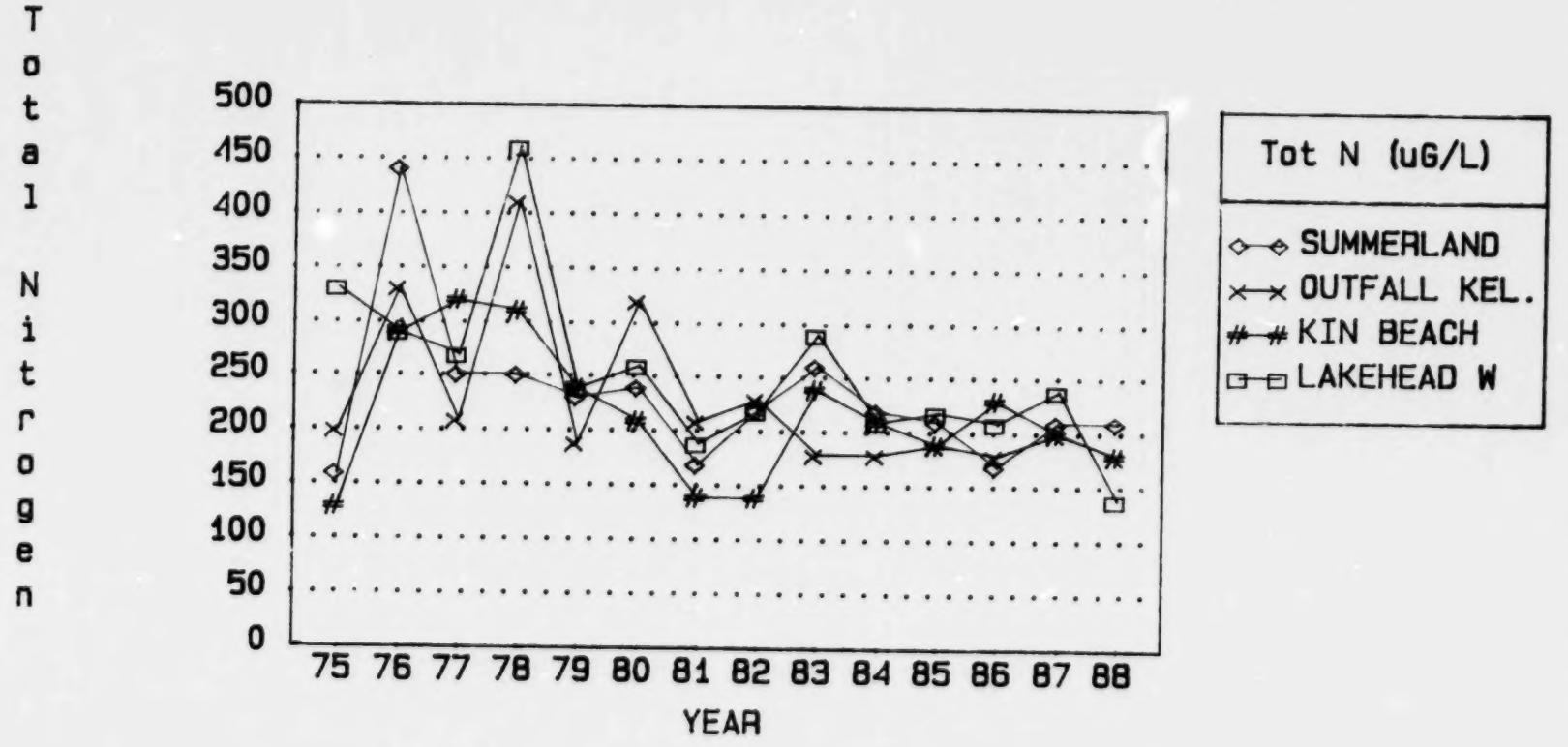


FIGURE 8. Spring total N in Okanagan

Lake @ 4 sites 6 to 11m deep. Values are 3-depth composites.



Phosphorus: Nitrogen Ratios

Phytoplankton production requires both nitrogen and phosphorus as nutrients; and the lack of either nitrogen or phosphorus limits productivity. Phosphorus limitation occurs when the nitrogen to phosphorus ratio in water is greater than 15 to 1 (Nordin 1985). Nitrogen is the limiting nutrient when the ratio is 5:1 or less. At intermediate ratios (between 15:1 and 5:1), there is either co-limitation by both nitrogen and phosphorus or else the limiting nutrient switches from one to the other. In Okanagan Lake phosphorus was usually limiting except in Armstrong Arm and near the outfalls from sewage treatment plants (Table 6). Nutrient addition experiments showed that nitrogen limitation occurred only in Armstrong Arm and during the early 1970's in Vernon Arm (Anon. 1974b). In other parts of Okanagan Lake, phosphorus addition was required to stimulate phytoplankton growth.

Autumn Phytoplankton

Spring phosphorus concentration determines the amount of phytoplankton growth later on in the season (Nordin 1985). In general, parts of Okanagan Lake with high spring phosphorus concentrations produced dense phytoplankton populations (Figure 9). The plots of phytoplankton show chlorophyll a in ug/L multiplied by 10 to eliminate the decimal place so that the plotting program would accept the data; thus for Figure 9, the data range from 0.5 to 3.4 ug/L. Armstrong Arm had a denser phytoplankton population than other parts of Okanagan Lake. Vernon Arm also had dense phytoplankton until Vernon's outfall was removed. After removal, phytoplankton was low and comparable to the other sites in Okanagan Lake.

Near Kelowna, the phytoplankton densities were similar to those in the main body of Okanagan Lake (Figure 10). There was approximately 1 microgram per litre of chlorophyll a when autumn sampling occurred. The phytoplankton samples do not reflect any change resulting from Kelowna's Bardenpho system in 1983. There was no difference in phytoplankton between shallow sites near versus far from outfall nor between the deep sites upstream versus downstream of the outfall.

Figure 11 shows phytoplankton at several shallow sites in Okanagan Lake. At the shallow sites near deep water, the concentrations of phytoplankton were roughly the same as those at the deep sites. In Armstrong Arm and Vernon Arm, however, phytoplankton levels were slightly higher than the other shallow sites. In the case of Vernon Arm, the populations decreased after 1977 when the sewage discharge stopped and full-scale spray irrigation began.

Phytoplankton densities were also sampled in the spring at the same time as nitrogen and phosphorus. In general, these phytoplankton levels were about twice as high as in the autumn. However, the patterns of difference among the stations were quite similar in the spring and the autumn data. Consequently, there is little point in presenting plots for both autumn and spring, so the autumn data are presented here.

FIGURE 9. Autumn phytoplankton, Okan.

Lake @ 5 sites. Values are epilimnion (0-10 m) composites.

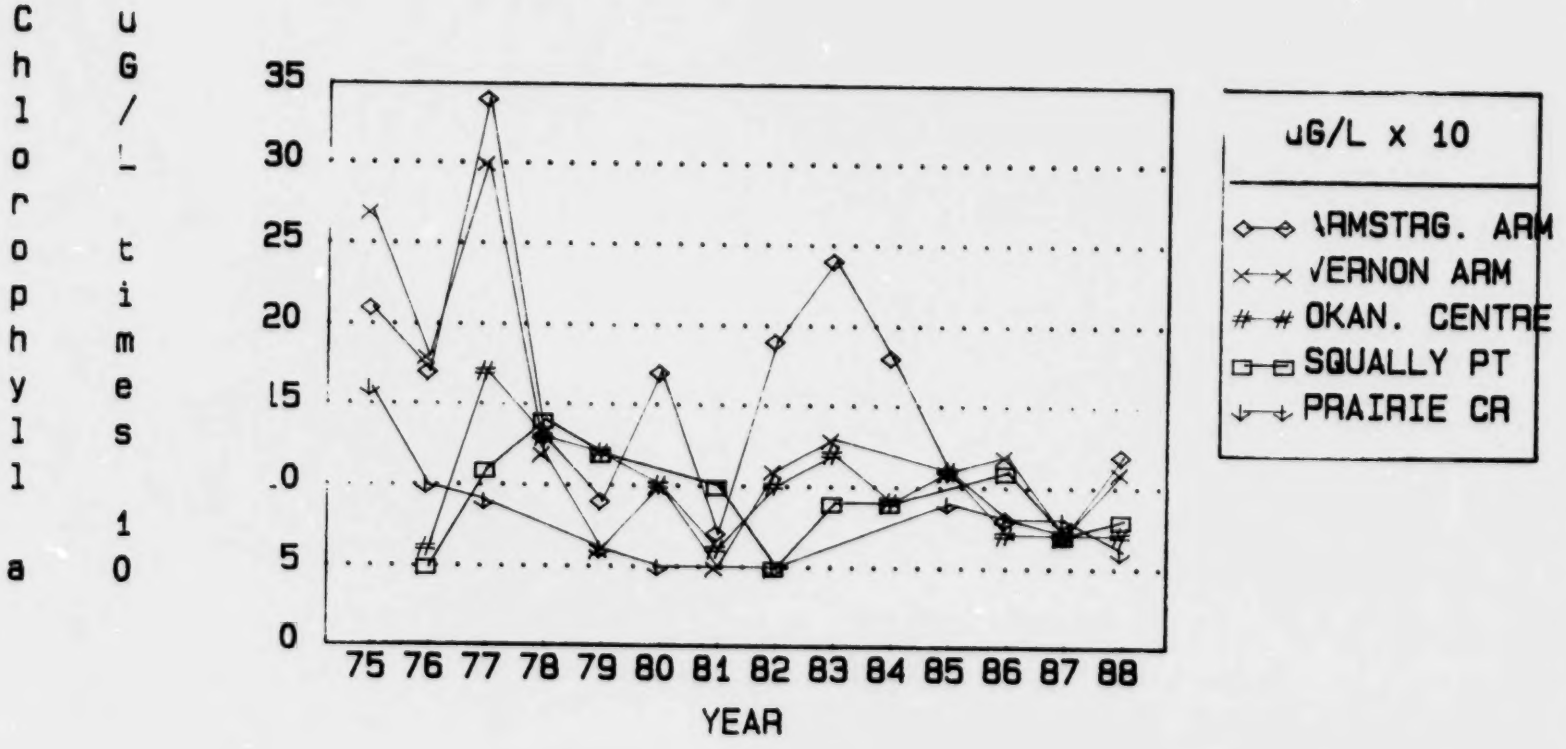


FIGURE 10. Autumn phytoplankton, Okan.

Lake near Kelowna's outfall. Values are composites @ 2, 4, 6m.

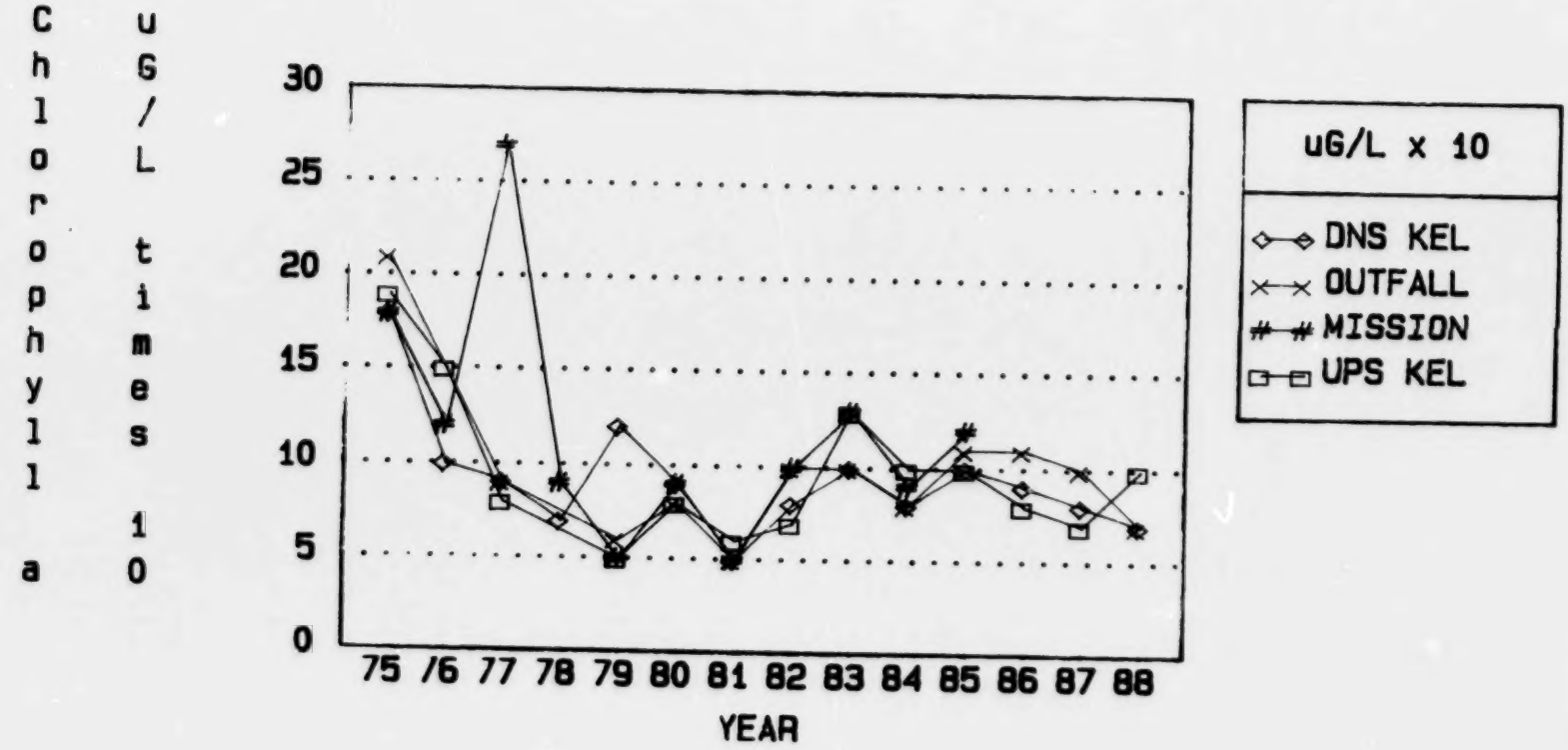
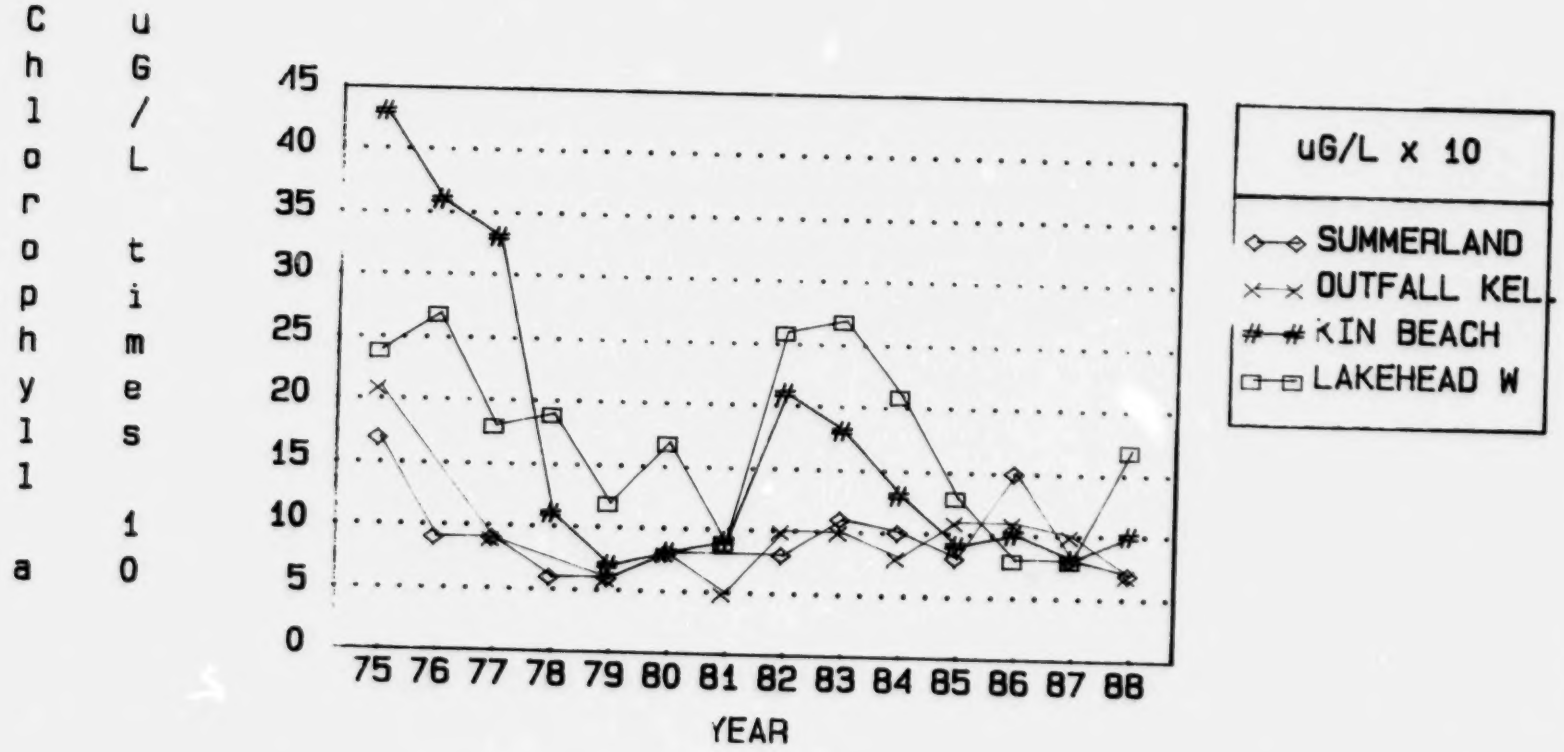


FIGURE 11. Autumn phytoplankton, Okan.

Lake @ 4 sites 6-11m deep. Values are composites @ 2, 4, 6m.



Other Trends in Water Quality

Table 7 shows a summary of trends in a number of different parameters in Okanagan, Kalamalka, and Wood Lakes. The data are groups of all information for several sites for each parameter over the time period of measurements by Waste Management (through 1988). Plots with interesting trends and plots for important parameters are presented in Appendix Figures 1 to 6. For specific sites, the means, sample sizes, and standard errors are presented in Appendix Tables 3 to 6.

For many data sets, there were outlying points. Some of these outlying points were mistakes: clerical errors, analytical errors, or contaminated samples. When such outliers occurred they changed the scale to which all the other points were plotted. Thus for some of the plots it was impossible to detect trends. Consequently outliers were omitted from most data sets as indicated on the plots. Particularly for metals, outliers were left in the data set even though these points, which may be erroneous, sometimes determine the slope of the regression.

For nutrients, the data sets were biased by inclusion of samples in summer and autumn when nutrients were generally low (Table 7). As a result, the patterns of abundance that are evident in sets of spring data are not always apparent in these plots. The most striking trend in a nutrient, was for ammonia. All sites in all lakes showed strong decreases in ammonia. No explanation for decreasing ammonia is readily apparent.

Okanagan Lake has increased in dissolved minerals during the period of observation (Table 7). Sodium, chloride, sulphate, magnesium, and calcium have all generally increased in Okanagan Lake. Strangely enough there has not been a clear increase in dissolved hardness. If one looks at a period of record even further back, the increase in sodium is even more apparent. This is shown by the data in Table 8. When the lake was examined by Rawson, sodium was lower than for all subsequent observations. Sodium has increased in Okanagan Lake partly because of inflows from Kalamalka Lake which is higher in sodium (Table 5).

Waste Management observations suggest that the water of Okanagan Lake has become clearer over the period of record (Appendix Figure 1-23). If real, this increase has been slight. In July and August 1935, the Secchi disc depth ranged from 8-10 m offshore of Mission (Clemens, Rawson, McHugh, 1939). For July to September 1973-88, the site nearest this location ranged from 7 to 12 m with an average of 8.9 m ($n = 17$). It is possible that the increasing trend for Secchi depths results at least in part because the lakes were sampled earlier in the spring (February versus March-April and later in the autumn (September versus August) starting about 1979. Both shifts in sampling time would have resulted in clearer water.

TABLE 7

Trends in water quality of Okanagan, Kalamalka and Wood Lakes. All data for a site, or group of sites were plotted in all years, seasons, and depths (except oxygen). Increasing trends are indicated by +, decreasing trends by -, and trends with little or no slope by 0. An I indicates inadequate data sets; an * indicates outlying extremes which often affected the regression line. For important parameters and those with strong trends, the plots are presented in Appendix Figures 1-5.

OKANAGAN LAKE

LAKE/LOCATION: (Number of Sites):	Main Basin (5)	Vernon Arm (2)	Armst. Arm (2)	Kelowna STP (1)	KAL. LAKE (5)	WOOD LAKE (2)
PARAMETER						
Biological:						
Carbon, total organic	-	-	-	-	-	I
Chlorophyll A	-	-	0	-	0	-
Coliform, fecal	0*	-*	-*	-*	0*	0*
Macronutrients:						
Nitrogen, total	0	-	0	+	+	-
Nitrogen, organic	+	-	-	+	+	-
Nitrogen, ammonia	-	-	-	-	-	-
Nitrate and Nitrite	+	+*	0	+	+	-
Nitrate	I	I	I	I	I	I
Phosphorus, total	-	-	+	+	+	-
Phosphorus, dissolved	0	-	-	+	-	-
Potassium	0	0	+	+	0	+
General ions:						
Acidity	+*	+	+	+	+*	+
Alkalinity, phen.	-*	-	-	-	-	-
Alkalinity, total	0*	0	0	0	0	0
pH	-	-	-	-	-	-
Boron, dissolved	I	-	-	I	-	I
Calcium, total	+	+	+	+	+*	+
Calcium, dissolved	I	+	+	I	+	-
Magnesium, total	+	+	+	+	I	+
Magnesium, dissolved	I	+	+	+	+	+
Hardness, dissolved	I	0	0	-	-	0
Chloride	+	+	+	+	+	+
Fluoride	I	I	I	I	I	I
Residue, total	I	-*	-	-	-	-
Residue, filterable	I	-	+	+	0	-
Silica	+	+*	+	+	-	+
Sodium	+	0*	+	I	+	-
Sulphate, dissolved	+	+	-	+	-	-
Physical						
Carbon, inorganic	+	I	+	+	+	0
Color	+*	+	+	-*	+*	0*
Oxygen (hypolimnion)	+	0*	0	I	0	+
Secchi depth	+	+	+	+	0	+
Specific conductance	-	-	-	-	+	-
Turbidity	-	-*	+*	+*	-*	-*

TABLE 7 continued

Trends in water quality of Okanagan, Kalamalka and Wood Lakes. All data for a site, or group of sites were plotted in all years, seasons, and depths. Increasing trends are indicated by +, decreasing trends by -, and trends with little or no slope by 0; an I indicates inadequate data sets; an * indicates outlying extremes which often affected the regression line. For important parameters and those with strong trends, the plots are presented in Appendix Figures 1-5.

OKANAGAN LAKE

LAKE/LOCATION: (Number of Sites):	Main Basin (5)	KAL. LAKE (5)	WOOD LAKE (2)
PARAMETER			
Other metals:			
Aluminium	+*	0*	-*
Arsenic	I	0*	-*
Cadmium	I	0*	I
Chromium	I	I	-*
Cobalt	I	I	I
Copper	-*	-*	-*
Iron	+*	-*	-*
Manganese	-*	I	-*
Molybdenum	-	I	-*
Nickel	I	I	-*
Lead	I	I	-*
Vanadium	I	I	I
Zinc	0*	0*	I

Another striking feature of Table 7 is that acidity has increased in all lakes while phenolphthalein alkalinity and pH have decreased. These changes were very slight, but they may be important. All of them are in the direction to be expected if they had been brought about by acidic precipitation. As documented by Anonymous (1988) precipitation in the Okanagan is on the acid side of neutral (pH 5). The Kelowna airport had the sixth highest acidity of the 13 locations monitored. Of these locations, Victoria had the most acidic rainfall (pH 4.6) and Cranbrook had the least acidic (pH 6.1). It may be worthy of note that aluminium generally increased in Okanagan Lake, although it is possible that this result was spurious because of the erratic nature of the few aluminium concentrations measured. Aluminium can be moved from soil and rock into surface waters because of acidic precipitation.

Although Okanagan Lake was classified oligotrophic by both the Okanagan Basin Study and the Okanagan Basin Implementation Study, it has become less oligotrophic in recent decades. Carbon profiles of Okanagan Lake sediments show enrichment during the last 70 years (Anon. 1974b). Moreover, the density of zooplankton increased 3 to 4-fold between 1935 and 1971. As described previously, water quality improved when wastewater was removed at Vernon and upgraded at Kelowna.

TABLE 8

Comparison of data for site 0500456 north of Kelowna with other data collected in the same general part of Okanagan Lake. Data for 1940-67 are given in Anon 1973. Except for pH, units are mg/L.

	April 28 1936 (Clemens)	1940-41 (Rawson)	1965-67 Average Station D-8	Average for 1975-80	Average for 1981-88
pH - Surface	8.0	8.2	8.0	8.2	8.1
- Bottom	7.8	7.8	-	8.1	7.9
Sodium	-	6.7	7.8	9.5	9.7
Calcium	28.7	31.2	32.7	32.7	33.5
Magnesium	0.0	7.6	8.7	8.3	8.8
Sulphate	48.0	19.8	25.5	28.2	28.2
Chloride	-	0.0	1.25	1.3	1.72
Alkalinity (C_3ACO_3)	-	103.2	104.5	-	108.2
Carbonate	131.0	126.0	-	-	-
Silica	3.9	34.2	6.7	4.2	5.06
Nitrate	0.00	-	.012	.022	.048
TOTAL SOLIDS	145	174	160	164	

2. Kalamalka Lake - Spring Phosphorus

The pattern of spring phosphorus in Kalamalka Lake has been somewhat cyclical (Figure 12). Phosphorus was quite low at all of the sites from 1973 to 1978. From 1979 to 1986 it was high at most sites and in 1987 and 1988 it was low again. For the most part, the sites increased or decreased in phosphorus concentration together; i.e. there was less variation in phosphorus concentration among all sites in any one year than at any site among all years.

There were significant upward trends in the regression equations for two of the three sites (Table 6). At the South End and the Deep Basin, there were significant trends. Whereas for Coldstream Creek, the trend was upward but not statistically significant.

Spring Total Nitrogen

Spring total nitrogen in Kalamalka Lake did not follow the same pattern as spring phosphorus (Figure 13). The values in different years were quite variable among the sites. There was at least as much variation among the sites in any one year as there was among the years. There was a slight upward trend at most of the sites, but no single site had a statistically significant trend.

Nitrogen to phosphorus ratios indicated that Kalamalka Lake was almost always limited by phosphorus (Table 6). Nutrient addition experiments confirmed that there may be some nitrogen limitation in Kalamalka Lake but in general both phosphorus and nitrogen must be added to stimulate growth of phytoplankton (Anon. 1974a).

Autumn Phytoplankton

Autumn phytoplankton was similar at all three sites shown for Kalamalka Lake (Figure 14). Autumn phytoplankton increased during the same years when spring phosphorus concentrations were high and then diminished when spring phosphorus concentrations declined. This same pattern of abundance was evident for spring phytoplankton concentrations as well. As in Okanagan Lake the spring density of phytoplankton was about twice the autumn density.

FIGURE 12. Spring total P in Kalamalka

Lake @ 3 deep sites. Values are composites of all depths.

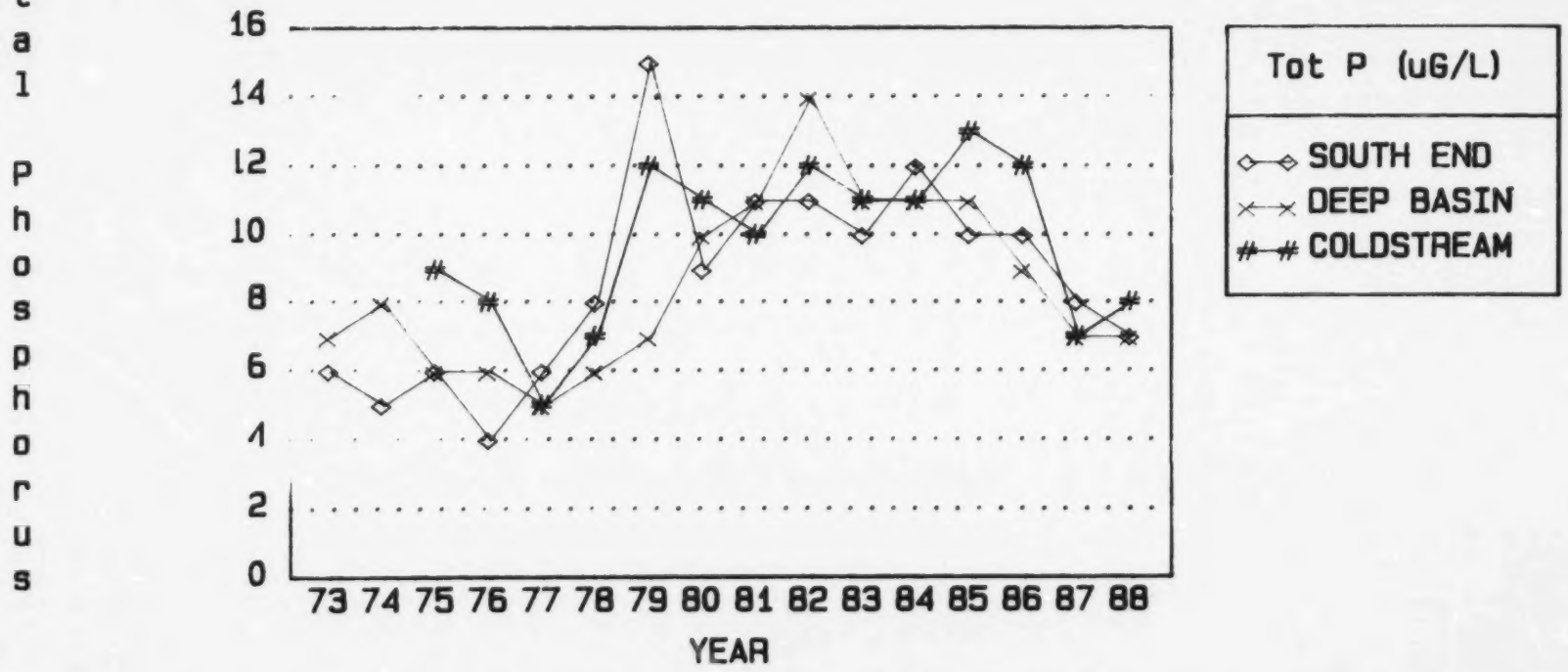


FIGURE 13. Spring total N in Kalamalka

Lake @ 3 deep sites. Values are composites of all depths.

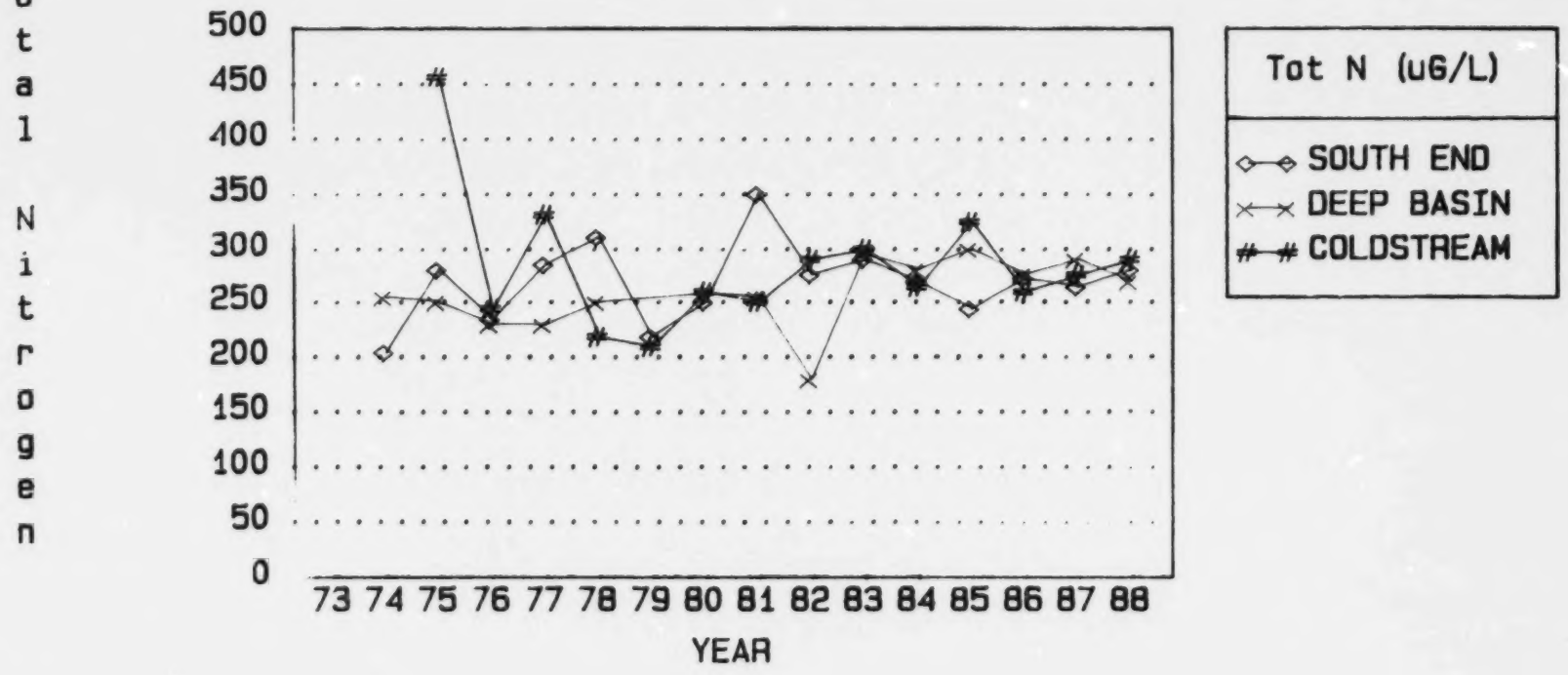
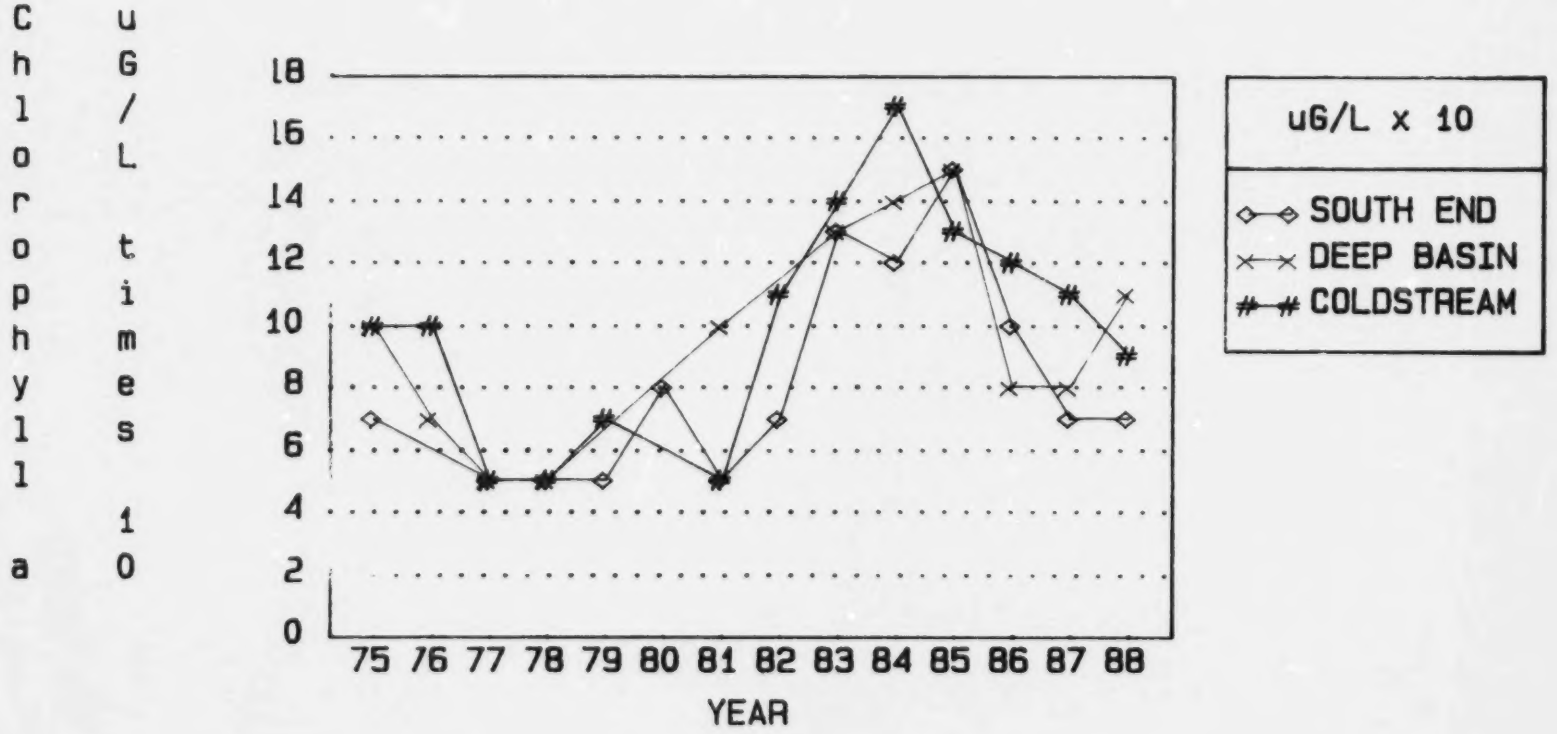


FIGURE 14. Autumn phytoplankton in

Kalamalka Lake. Values are epilimnion composites (0 - 10m).



Trends In Other Parameters

An important trend in Kalamalka Lake is a decline in pH over the years. This same trend was reported previously by Clark and Peppin (1984). A drop in pH presumably means that less marl is precipitated in Kalamalka Lake. Marl is important because it imparts the colors characteristic of Kalamalka Lake. Marl is also important because it removes phosphorus from the water column by binding phosphorus which co-precipitates in the marl sediment. Also relevant to marl precipitation is the finding that sulphate has decreased in Kalamalka Lake over the years (Table 7). Sulphate is a component of marl.

Extinction depth in Kalamalka Lake, as measured with a Secchi disc, remained unchanged during the course of observations. In the other lakes at all sites, Secchi disc depth showed an increase. Thus the water became slightly clearer in all lakes except Kalamalka. As discussed previously, any real increase in clarity is confounded with shifts in sampling times to when the lakes are likely to be clearer. As shown in Figure 14, Kalamalka Lake increased in phytoplankton perhaps offsetting potential increases in water clarity. Alternatively, perhaps the marl in Kalamalka Lake reduced light penetration into the lake even when phosphorus was low.

The Secchi disc depth was 6 and 7 m on August 13 and 14, 1935 near the south end of Kalamalka Lake (Clemens, Rawson, and McHugh 1939). At the two sites (246 and 579), August Secchi disc depths ranged from 3.8 m to 10.7 m with an average of 6.5 m (n = 12) for years from 1975 to 1988.

Another trend that possibly results from denser phytoplankton in Kalamalka Lake is the decrease in silica concentration. Silica is an important component of diatom skeletons, and the decrease may reflect that there has been greater diatom growth in Kalamalka Lake recently than in the previous decade.

The water quality data presented in this report indicate that the quality of Kalamalka Lake has deteriorated faster than the quality of Okanagan Lake. This is consistent with the fact that the Okanagan Basin Study classified Kalamalka Lake as ultra-oligotrophic and the most oligotrophic of the main valley lakes (Anon. 1974b). The Kalamalka-Wood Lake Study, which followed, classified it as oligotrophic approaching mesotrophic (Anon. 1974a). The Okanagan Basin Implementation Study classified it as oligotrophic (Anon. 1982). Either Kalamalka Lake was mis-classified in the Okanagan Basin Study or else the quality has deteriorated rapidly since then. Increasing phosphorus, phytoplankton, and periphyton indicate that Kalamalka Lake quality could continue to deteriorate.

3. Wood Lake - Phosphorus Concentration

Phosphorus concentrations decreased at both of the sites in Wood Lake (Figure 15). The concentrations of phosphorus in years 1984 to 1988 were much lower than for the earlier years. This decrease in total phosphorus concentration was statistically significant (Table 6). As with Kalamalka Lake, different sites were reasonably consistent in spring phosphorus concentrations in different years. In other words, there was less difference between the sites in any one year than at either site among the years.

Total Nitrogen

In Wood lake there is a downward trend in spring total nitrogen (Figure 16). Spring nitrogen in 1979 to 1988 was considerably lower than in earlier years, 1974 to 1977. Table 6 shows that this trend is statistically significant.

Only once was the nitrogen to phosphorus ratio 15:1 or greater (Figure 17). Thus in Wood Lake either or both phosphorus and nitrogen are usually the limiting nutrients. Phosphorus usually limits phytoplankton production in the other Okanagan lakes. In Wood Lake there is co-limitation by both nitrogen and phosphorus or else the limiting nutrient switches from one to the other. Most of the ratios from Wood Lake fell into the intermediate range of 15:1 to 5:1. As the ratio never fell below 5:1, these ratios do not show that nitrogen was the only limiting nutrient in Wood Lake. However, in 1971 enrichment with nitrogen alone was usually sufficient to increase the phytoplankton densities in Wood Lake (Anon. 1974a, 1974b).

Figure 17 shows that the N:P ratio decreased in about 1979 when total nitrogen also decreased. However, the ratio increased again in about 1984 when spring phosphorus began to decrease.

Autumn Phytoplankton

Autumn phytoplankton decreased markedly in the years 1975 to 1977 (Figure 18). Autumn phytoplankton has remained low in the years since then. The standing crop in Wood Lake is higher than in Kalamalka Lake and higher than in most locations of Okanagan Lake. Spring phytoplankton in Wood Lake also decreased but not as markedly as autumn phytoplankton. As with other lakes, the spring standing crop of phytoplankton was greater than the autumn standing crop even though the samples in the spring were taken when the lake was isothermal and as early as ice conditions permitted.

FIGURE 15. Spring total P in Wood L

@ 2 sites. Data are composites of all depths sampled.

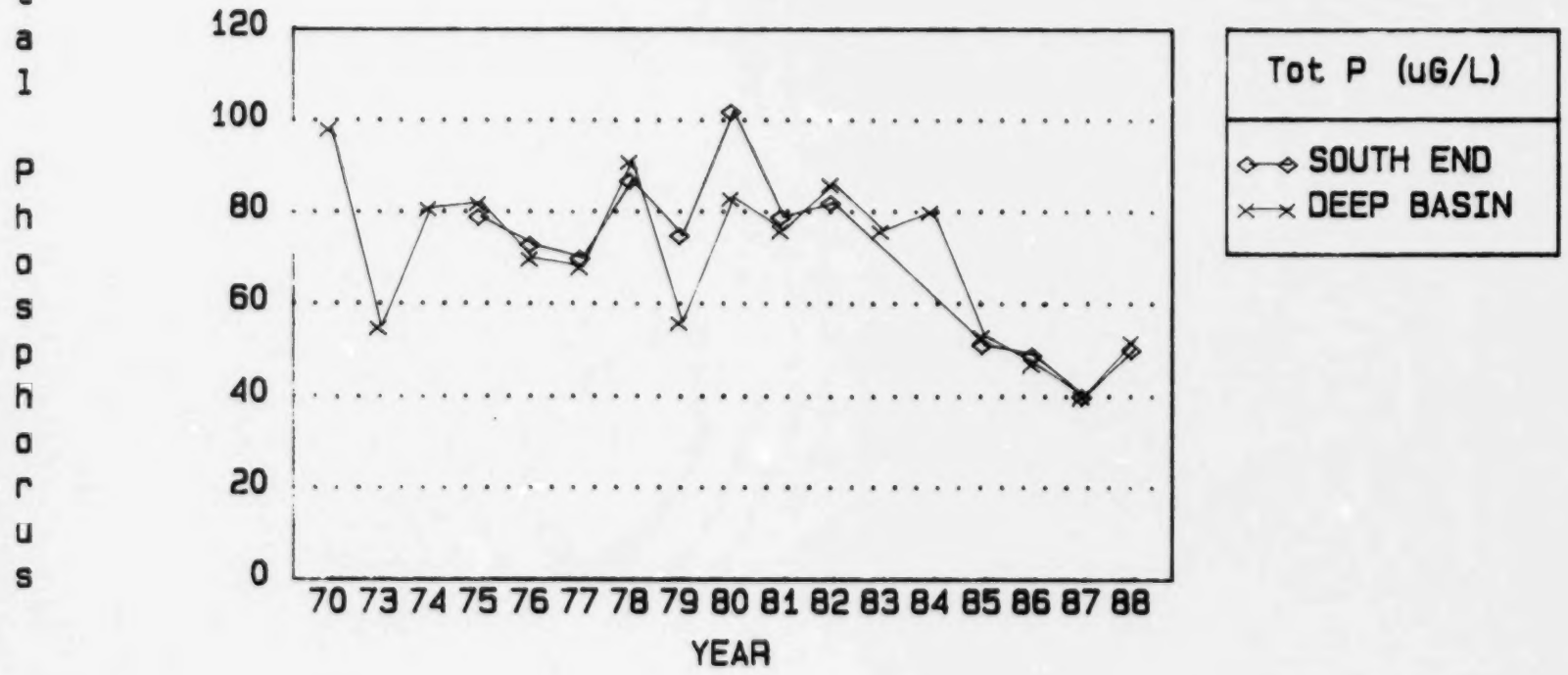


FIGURE 16. Spring total N in Wood L

@ 2 sites. Data are composites of all depths sampled.

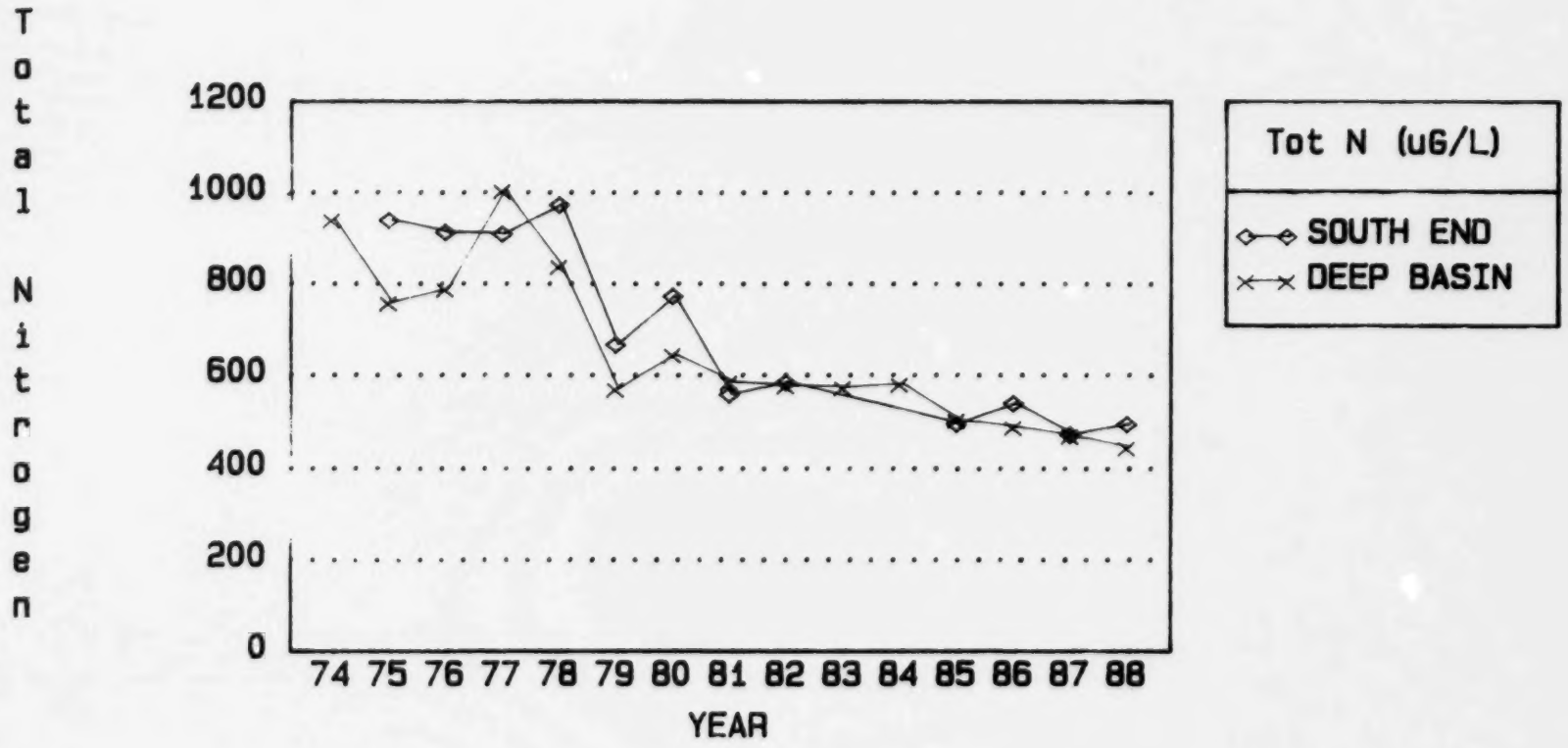


FIGURE 17. Spring N:P ratio for

Wood Lake @ Deep Basin (0500848).

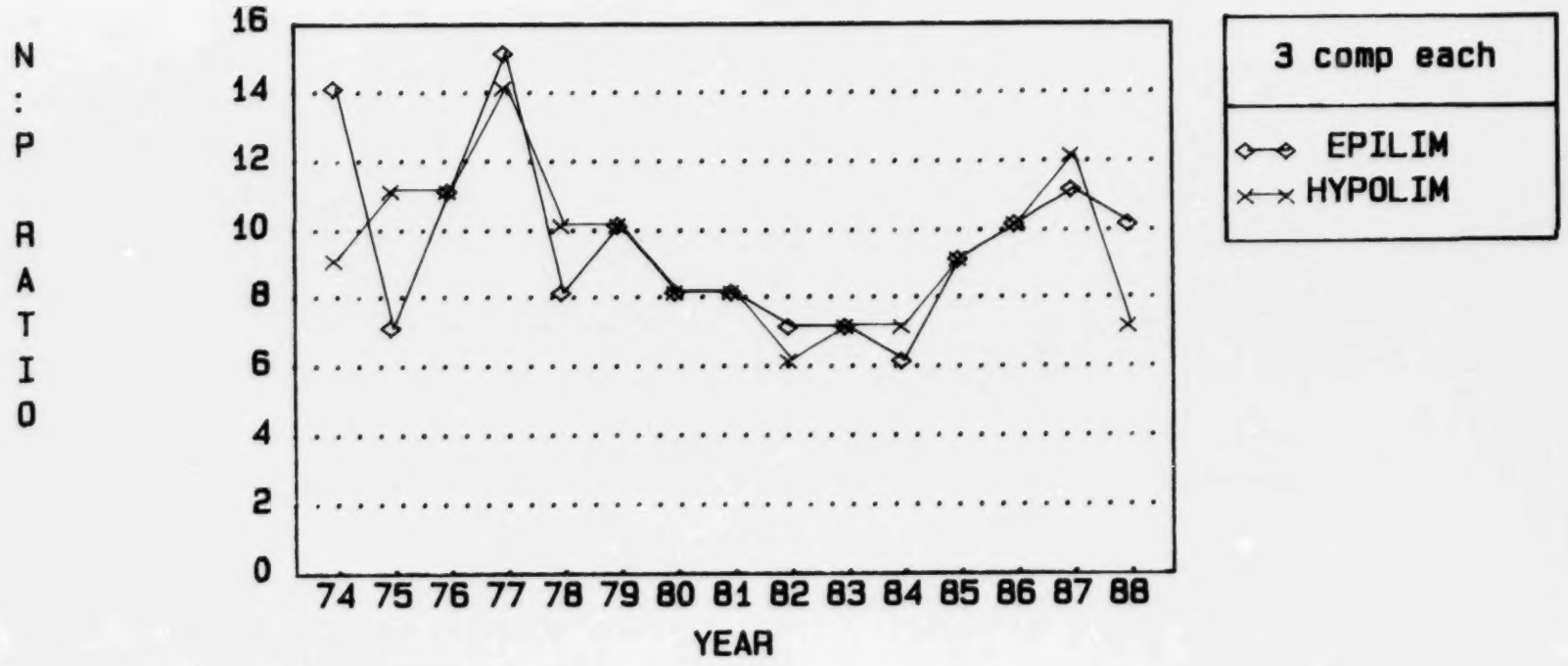
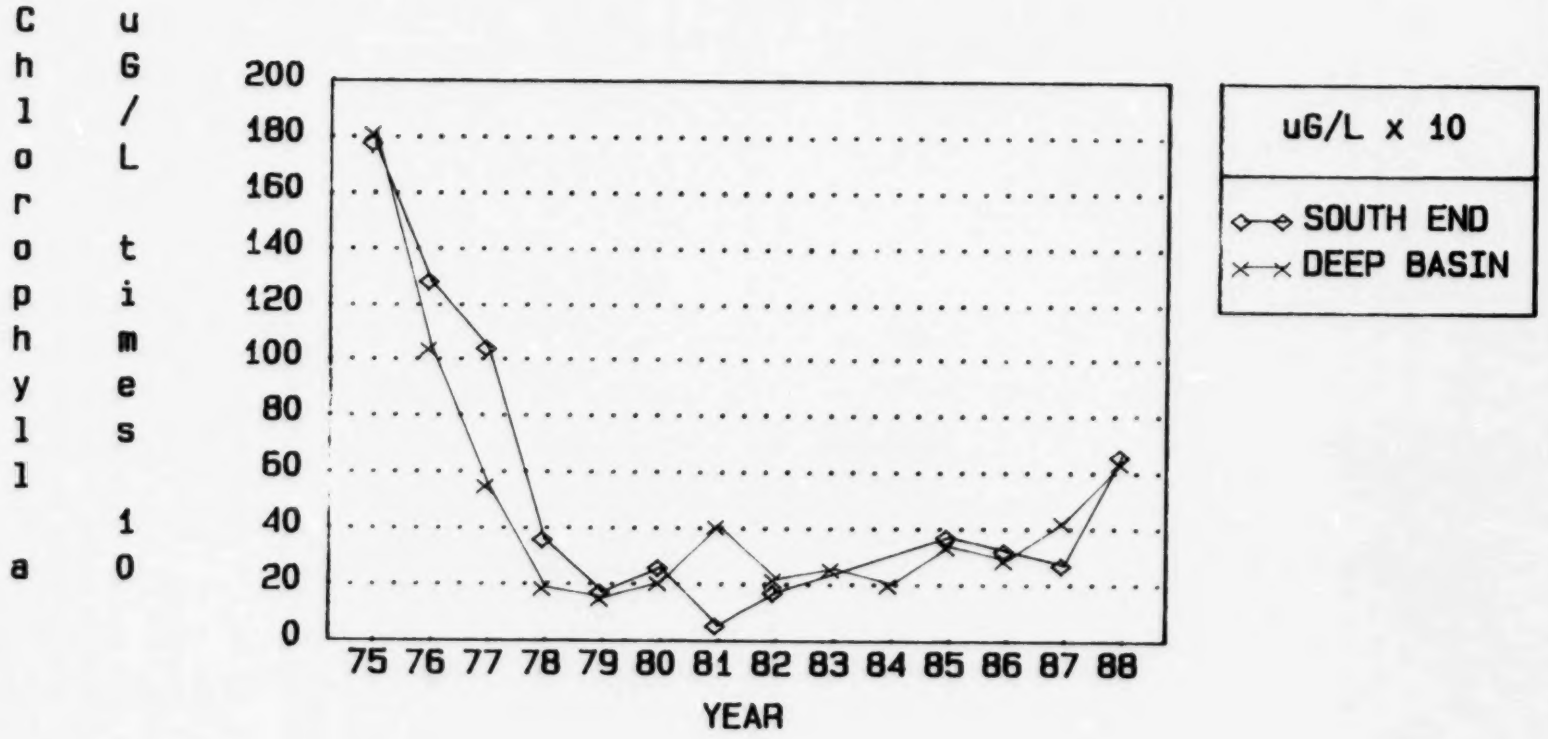


FIGURE 18. Autumn phytoplankton in

Wood Lake. Values are epilimnion composites (0-10 m)



Trends In Other Parameters

Improved water quality in Wood Lake was evidenced by changes in a number of other parameters. Water clarity greatly increased during the 15 years of observations by Waste Management (Table 7, Appendix Figure 5). The Secchi disk depth was much greater at the end of 1980's than it was in the 1970's. In addition, there was a substantial increase in hypolimnetic oxygen concentration in Wood Lake. In the 1970's, oxygen often diminished markedly in the summertime. Water deep in the hypolimnion was not only low in oxygen but high in hydrogen sulphide gas. As a result, there was probably a considerable amount of phosphorus released from the sediments back into the water column before 1978.

This increased the total amount of phosphorus available to phytoplankton in Wood Lake. With the higher oxygen levels which prevail in Wood Lake now, such flux of phosphorus from the sediment is much reduced. In addition, the hypolimnion is much more suitable for salmonid habitat and growth now than it was in the 1970's. Trout and kokanee require high oxygen concentrations in order to survive and grow. Their growth was more limited ten years ago than it is now. The increase in hypolimnetic oxygen is shown by Appendix Figure 6-15.

Water quality in Wood Lake deteriorated between 1935 and 1970. On August 13, 1935 the Secchi disc depth ranged from 2 to 2.5 m and the dissolved oxygen from 5.7 cc/L to 1.7 cc/L at the bottom (30 m; Clemens, Rawson and McHugh, 1939). In the early 1970's, usual Secchi depths were less than 2 m, and Wood Lake regularly produced an anoxic hypolimnion and generated hydrogen sulphide by mid-summer. Organisms living in hypolimnetic sediments in 1935, such as chironomids and oligochaetes, had been eliminated by 1971 (Anon. 1974b).

Since the mid 1970's, water quality in Wood Lake has been improving. Phosphorus, nitrogen and phytoplankton have been decreasing while water clarity and hypolimnion oxygen have been increasing. Wood Lake was classified as eutrophic during the Okanagan Basin Study, but only mildly eutrophic by the Okanagan Basin Implementation Study (Anon. 1974b, 1982). Part of the reason for improved water quality in Wood Lake is the introduction of low phosphorus water from Okanagan Lake by the cooling water system of Hiram Walker.

In 1974, it was predicted that the cooling water would improve the quality of Wood Lake and possibly lower the quality of Kalamalka Lake (Anon. 1974a). The water quality monitoring results in this report show that the predicted changes have occurred. However, the deterioration in Kalamalka Lake quality seems greater than expected from the additional phosphorus load due to cooling water alone. Therefore, it is possible that other cause(s) may be partly responsible for water quality trends Kalamalka and Wood Lake. Specific conductance, residues, and sodium concentration of Wood Lake have been decreasing (Appendix Figures 6-11, 12, 13, 17), due at least in part to dilution with water from Okanagan Lake.

C. WATER QUALITY OBJECTIVES FOR OKANAGAN LAKES

Water quality objectives for the Okanagan Lakes were set following a study done in 1985 (Anon. 1985). Phosphorus was the only water quality parameter for which an objective was set. The reason is that phosphorus usually limits biological growth in the Okanagan Lakes. It was thought that controlling phosphorus by setting specific targets for each lake would result in the achievement of other limnological conditions which were desirable. The water quality objectives were chosen to protect the most sensitive water use. The rationale for the objectives is discussed elsewhere (Anon. 1985 and Nordin 1985). The following sections describe the extent to which the objectives were achieved in each of the three lakes:

1. Okanagan Lake

To check for attainment of objectives, Okanagan Lake was separated into three basins: the main basins, Vernon Arm and Armstrong Arm. Table 9 shows that in the main basins, water quality objectives were met in all three years after they had been set. Thus water quality in the main body of Okanagan Lake is good. Likewise, in Vernon Arm, the spring phosphorus concentrations were less than the objective.

In Armstrong Arm, however, the objective was not met in any of the years. Water quality in Armstrong Arm will probably improve when the City of Armstrong upgrades its wastewater treatment plant. If there is a continuing input of phosphorus from Armstrong however, then water quality in Armstrong Arm will not improve by very much. Because Armstrong Arm is such a large area of shallow water, removing Armstrong's outfall by itself, may not be enough to achieve the water quality objective which has been set for Armstrong Arm.

TABLE 9

Comparison of spring phosphorus concentrations (ug/L) with objectives for Okanagan Lakes 1986-1988. The average concentrations include only sites deeper than 18 m as specified in the objectives document (Anon. 1985).

			AVERAGE CONCENTRATION IN YEAR		
LAKE	(BASIN)	OBJECTIVE	1986	1987	1988
Okanagan	(main basins)	10	7	6	7
	(Vernon Arm)	10	8	6	7
	(Armstrong Arm)	10	26	16	20
Kalamalka		8	10	8	7
Wood		15	48	40	52

In addition to an upgrade of the sewage treatment plant, the Okanagan Water Quality Control Project is attempting to curb nutrients from agriculture in the Deep Creek Basin. If this effort is successful, phosphorus loads in Deep Creek will be reduced. This also should result in improved water quality in Armstrong Arm.

It remains to be seen whether these two important changes will be sufficient to upgrade water quality to the level specified by the objective. Indeed, given that Armstrong Arm has many characteristics of other shallow water bodies in the Okanagan, such as Wood, Skaha and Osoyoos Lakes, it seems unlikely that these measures by themselves will be sufficient to reduce phosphorus levels to 10 micrograms per litre in the spring. Further measures may be needed to restore Armstrong Arm to the condition common to the rest of the Okanagan Lake.

2. Kalamalka Lake

In two of the three years, Kalamalka Lake met the water quality objective set for it (Table 9). As presented in the previous section of this report, phosphorus in Kalamalka Lake shows an overall increase. Consequently, it is uncertain whether the water quality objective will be met consistently during the next decade. Also, it remains unclear why phosphorus increased between 1978 and 1985 and what was responsible for the decrease since then. It is possible that the marl precipitation in Kalamalka Lake no longer operates as it did. Further investigations of Kalamalka Lake limnology are required in order to answer these questions.

3. Wood Lake

Table 9 shows that the water quality objective for Wood Lake was not met in any of the three years since the objective was set. Indeed, the concentrations are roughly three times the objective. There are no direct discharges to Wood Lake that could be upgraded or removed. Many of the diffuse source loadings have little possibility of being reduced. There is a moderate septic tank loading and it is possible that a common treatment system with phosphorus removal would reduce phosphorus from this source slightly. There are very few livestock operations in the watershed which could be improved in order to reduce phosphorus from livestock.

The Kalamalka and Wood Lake Study and the Okanagan Basin Implementation Study recommended that water quality in Wood Lake be restored with some sort of lake treatment system. Nordin (1987) planned to attempt to do this with the addition of ferric chloride to Wood Lake. Unfortunately, the limnological conditions in Wood Lake have been unfavourable for field trials of this material. In the last two years, Wood Lake has had marl precipitation during the

summer much the same as in Kalamalka Lake. Spring phosphorus levels in Wood Lake have declined. However, phosphorus concentrations observed in the spring are still more than 3 times the objective. Consequently, some other method(s) of lake restoration will have to be considered if the objective of 15 micrograms per litre for Wood Lake is to be met.

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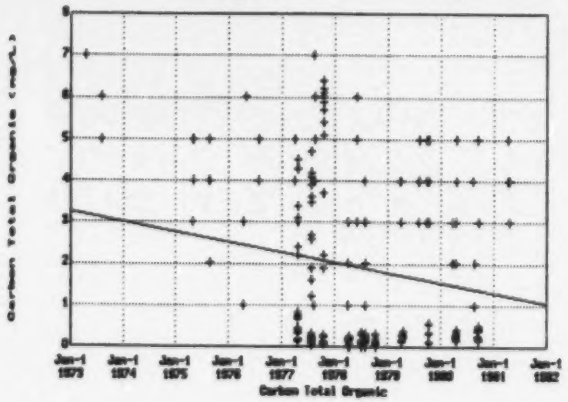
Appendix Figures (A.F.) 1-1 to 1-31. Okanagan Lake data for 5 sites (0500454, 0500729, 0500236, 0500456 and 0500730) which are in deep water of the main body and well removed from discharges and diffuse sources of contaminants. Plotted are all data stored on SEAM or EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

A.F. 1-1 Okanagan Lake - 5 Deep Sites



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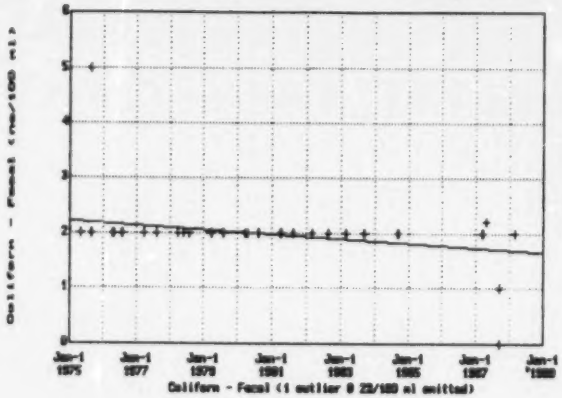

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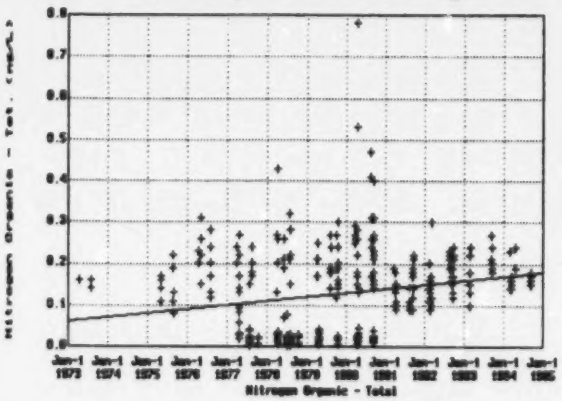

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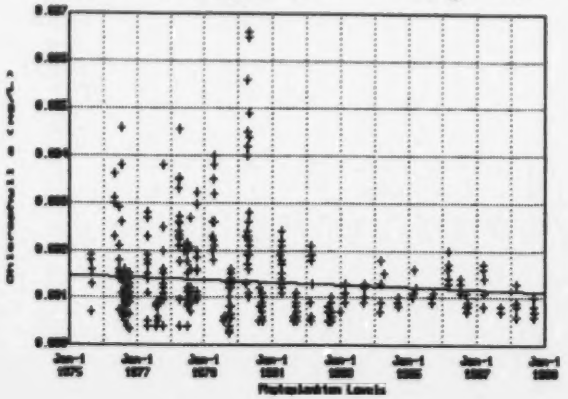

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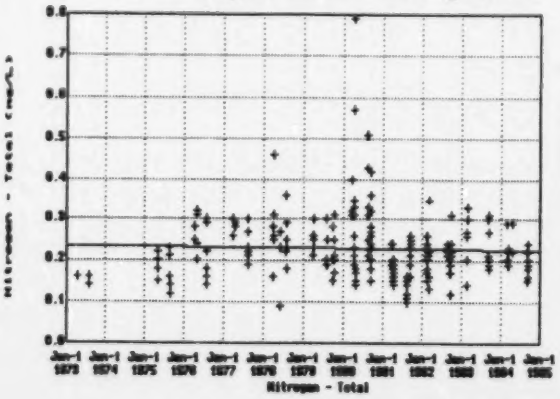

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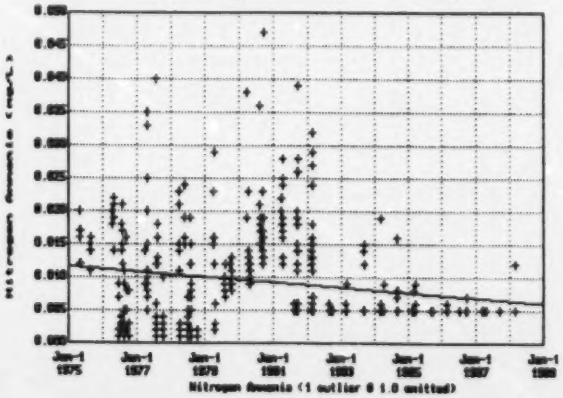

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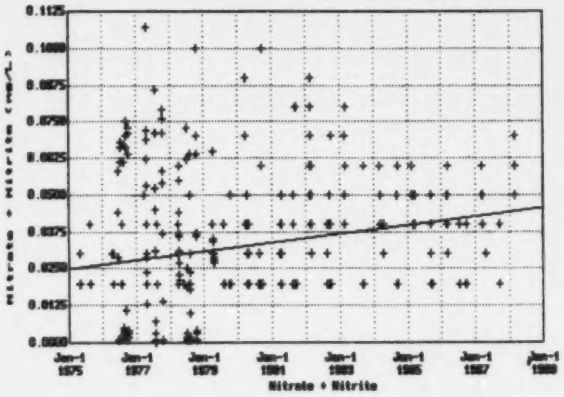
A.F. 1-7 Okanagan Lake - 5 Deep Sites



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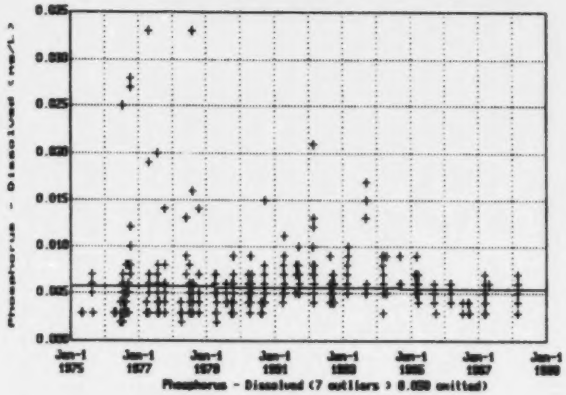

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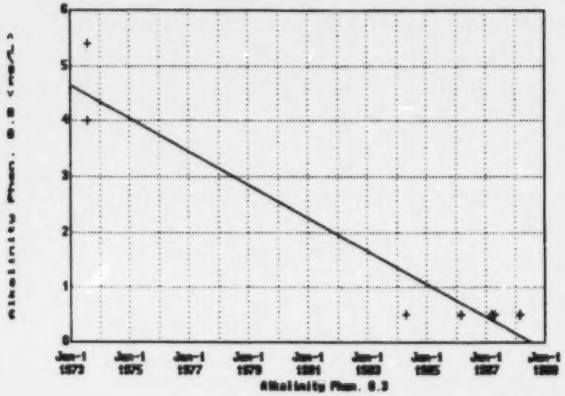

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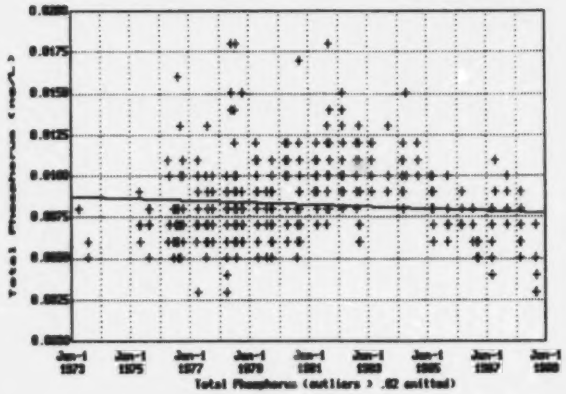

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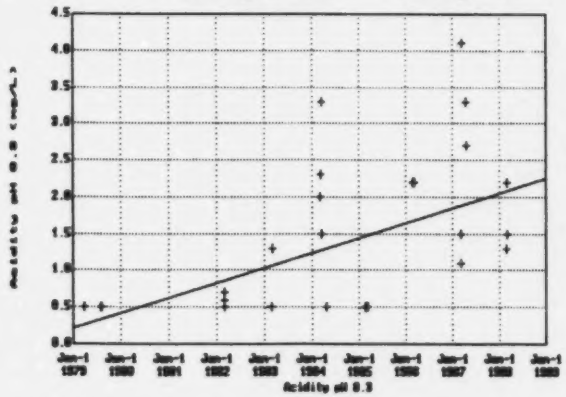

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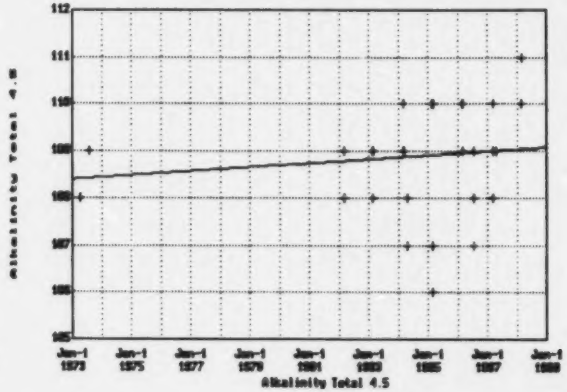

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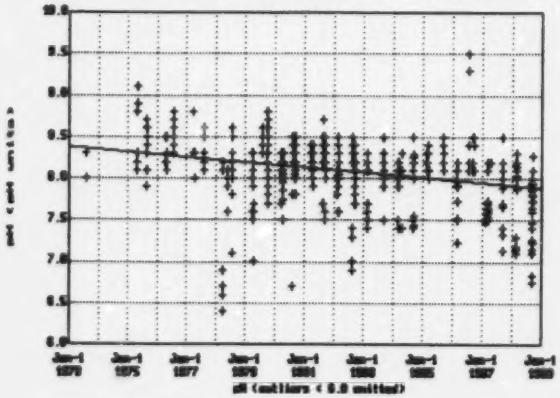

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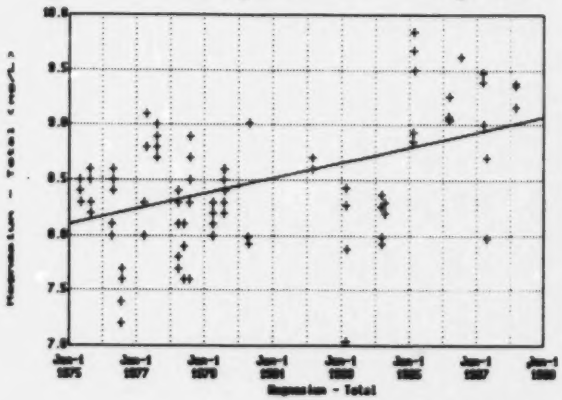

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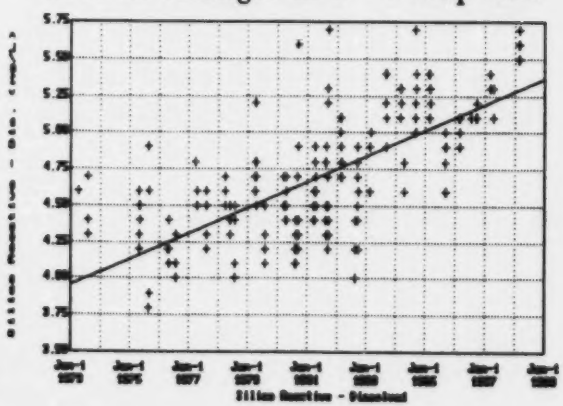

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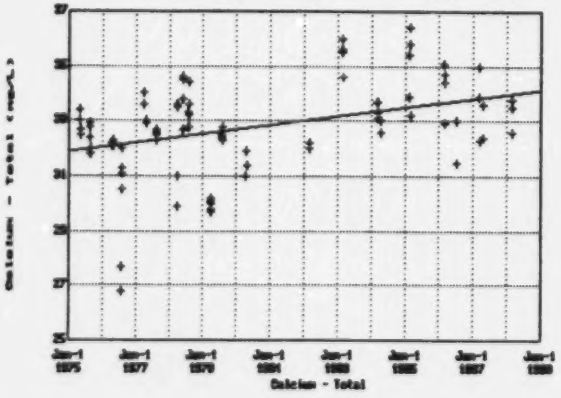

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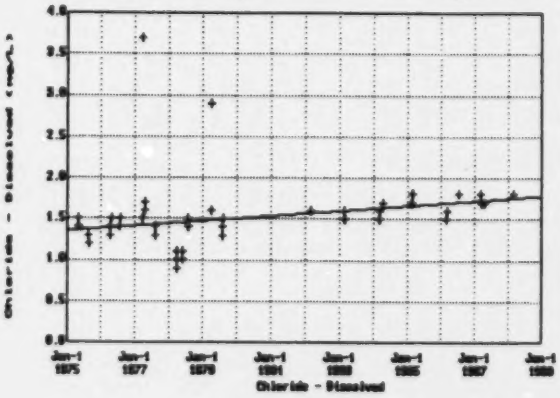

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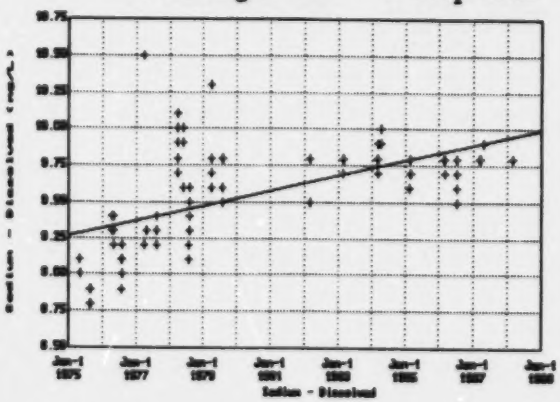

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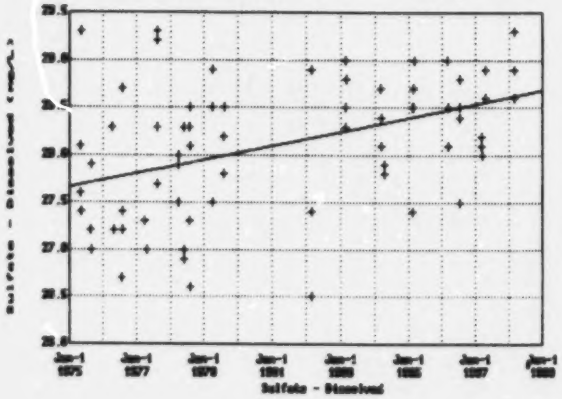

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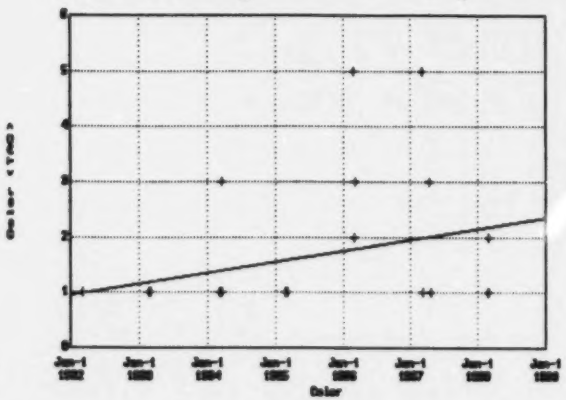

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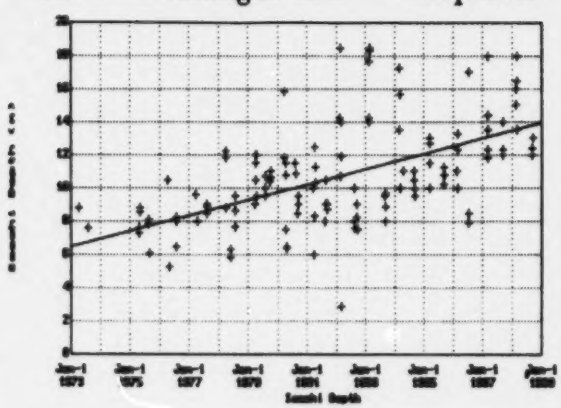

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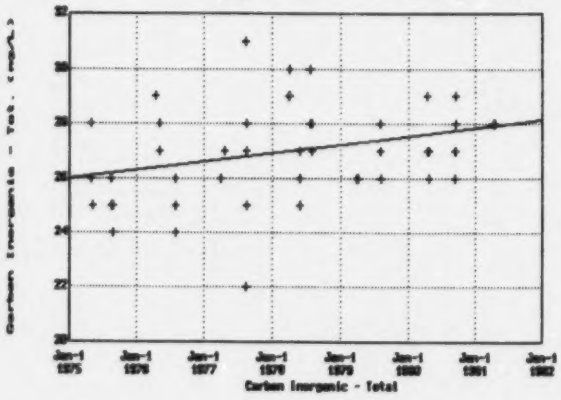

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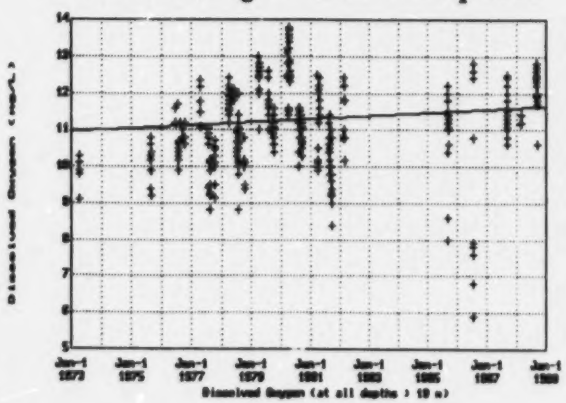

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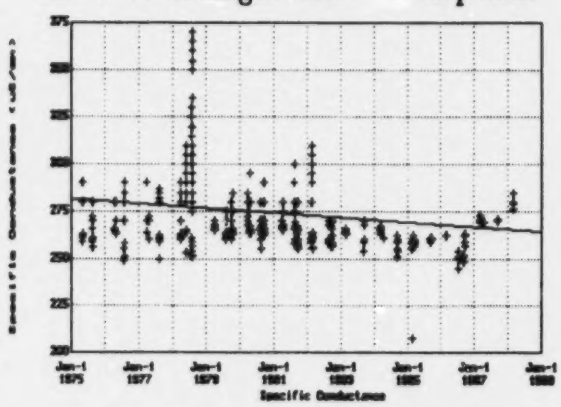

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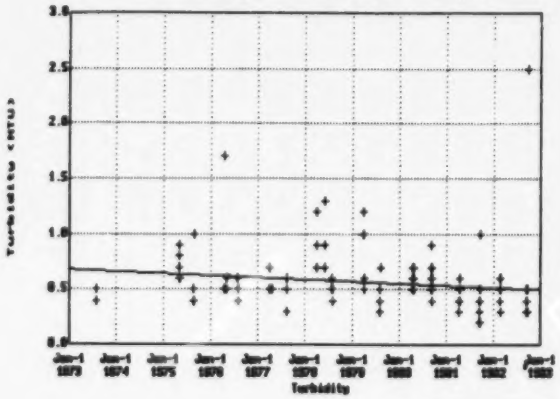

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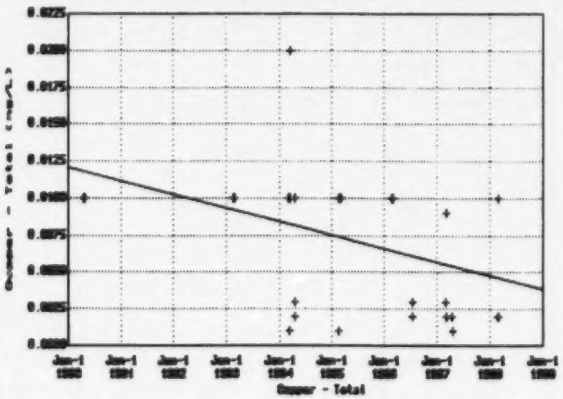

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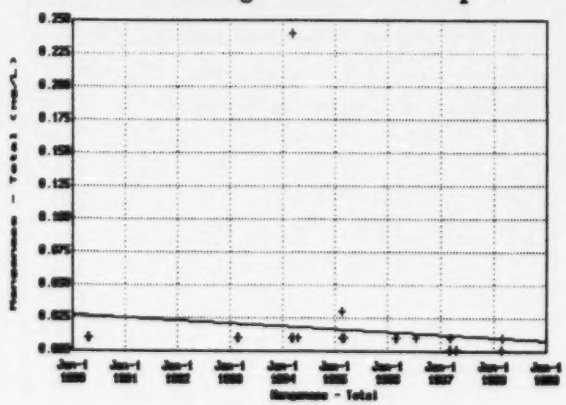

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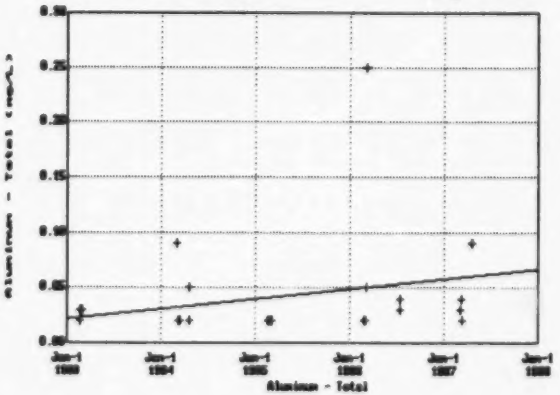
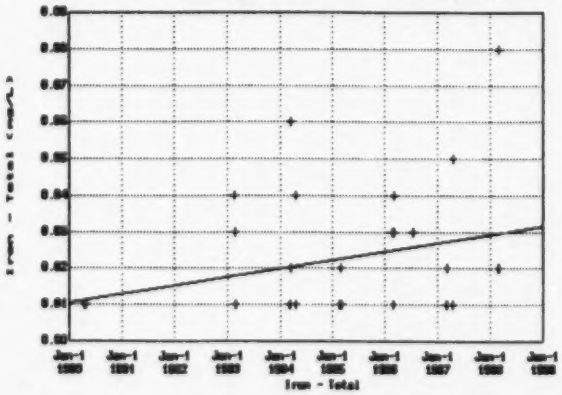
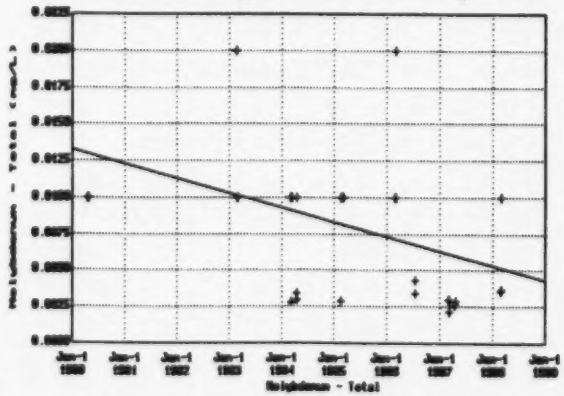


A.F. 1-28 Okanagan Lake - 5 Deep Sites

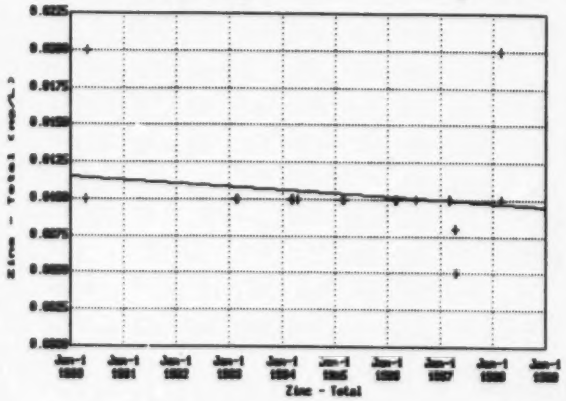


A.F. 1-30 Okanagan Lake - 5 Deep Sites

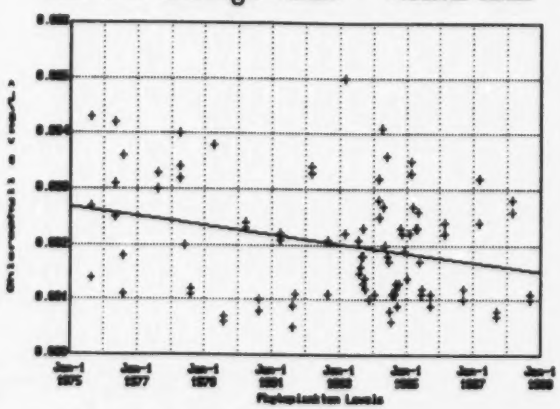


Appendix Figures (A.F.) 2-1 to 2-18. Okanagan Lake data for 2 sites in Vernon Arm (0500458 and 0500238). Plotted are all data stored on SEAM or EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

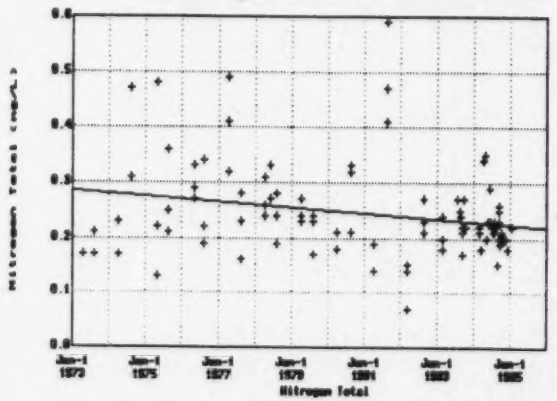
A.F. 1-31 Okanagan Lake - 5 Deep Sites



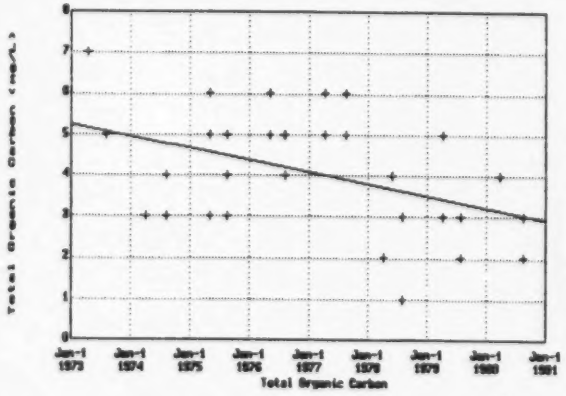
A.F. 2-2 Okanagan Lake - Vernon Arm



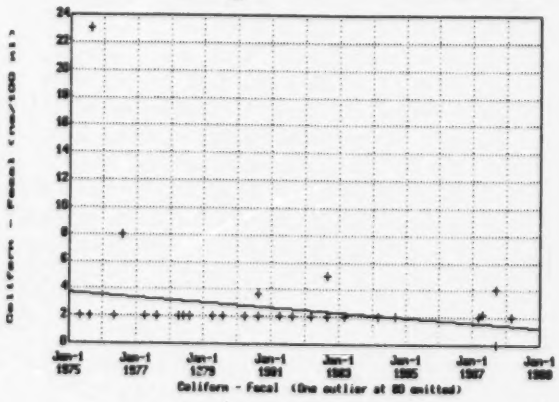
A.F. 2-4 Okanagan Lake - Vernon Arm



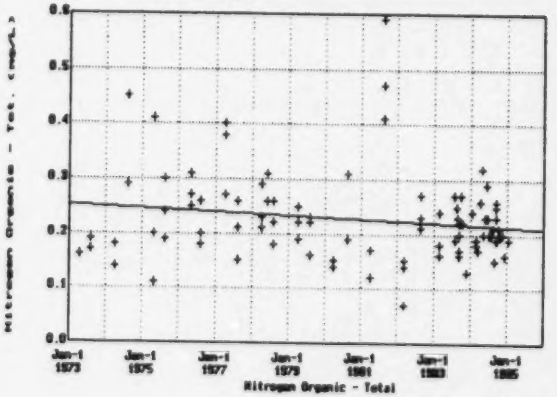
A.F. 2-1 Okanagan Lake - Vernon Arm



A.F. 2-3 Okanagan Lake - Vernon Arm

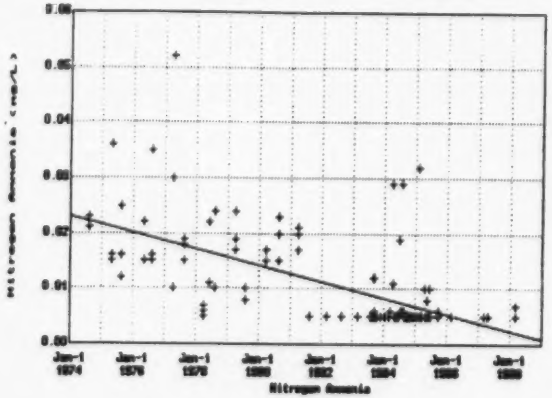


A.F. 2-5 Okanagan Lake - Vernon Arm

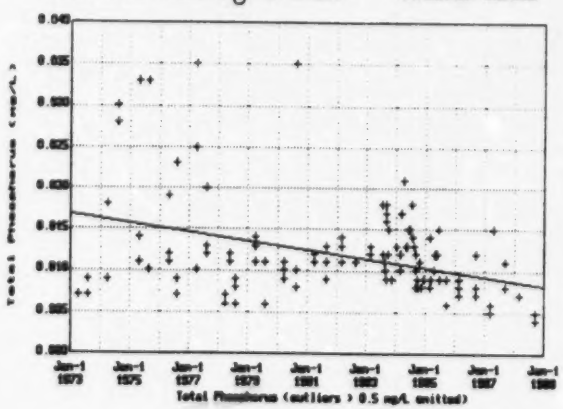


Appendix Figures (A.F.) 2-1 to 2-18. Okanagan Lake data for 2 sites in Vernon Arm (0500458 and 0500238). Plotted are all data stored on SEAM or EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

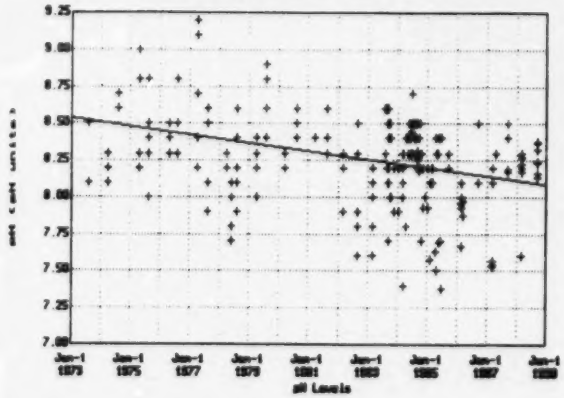
A.F. 2-6 Okanagan Lake - Vernon Arm



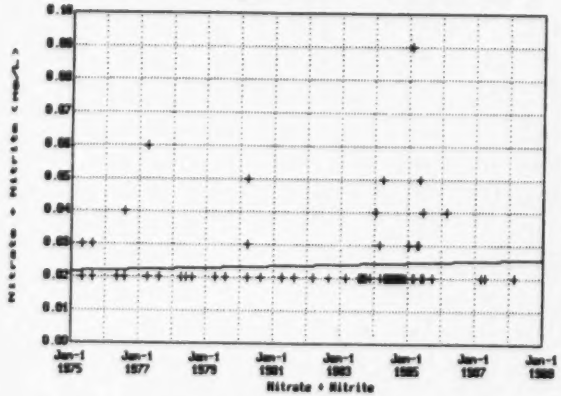
A.F. 2-8 Okanagan Lake - Vernon Arm



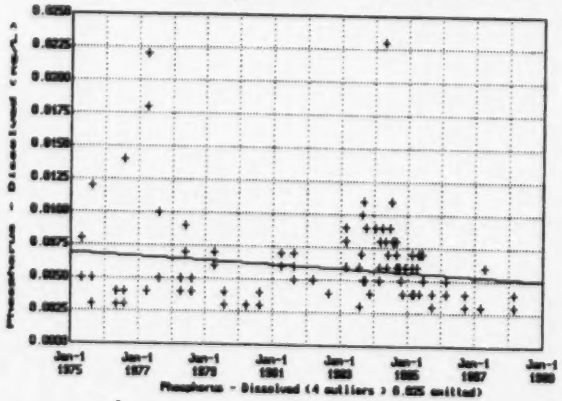
A.F. 2-10 Okanagan Lake - Vernon Arm



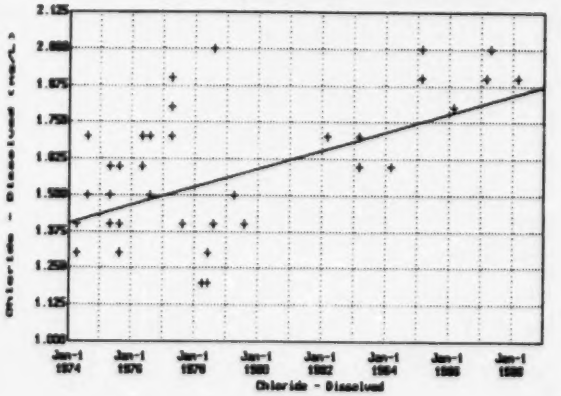
A.F. 2-7 Okanagan Lake - Vernon Arm



A.F. 2-9 Okanagan Lake - Vernon Arm

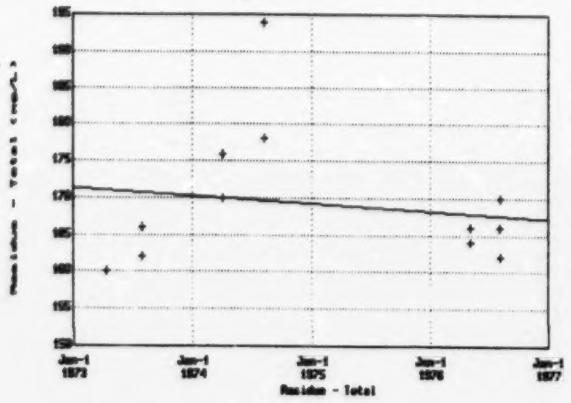


A.F. 2-11 Okanagan Lake - Vernon Arm

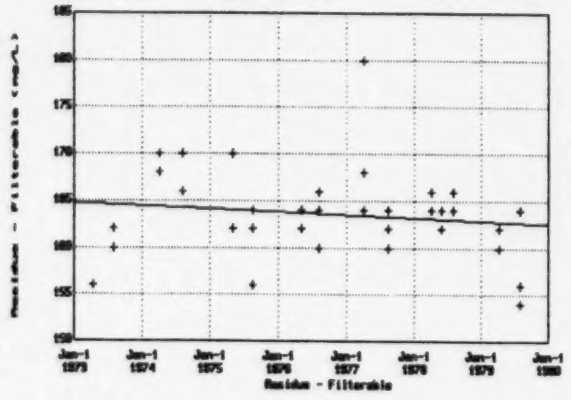


Appendix Figures (A.F.) 2-1 to 2-18. Okanagan Lake data for 2 sites in Vernon Arm (0500458 and 0500238). Plotted are all data stored on SEAM or EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

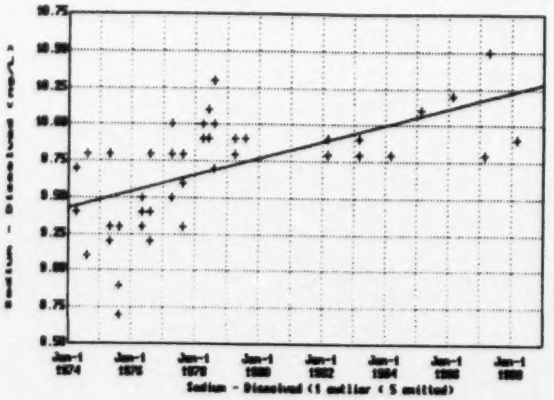
A.F. 2-12 Okanagan Lake - Vernon Arm



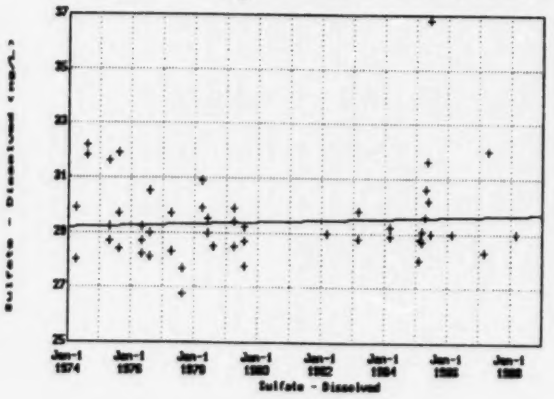
A.F. 2-13 Okanagan Lake - Vernon Arm



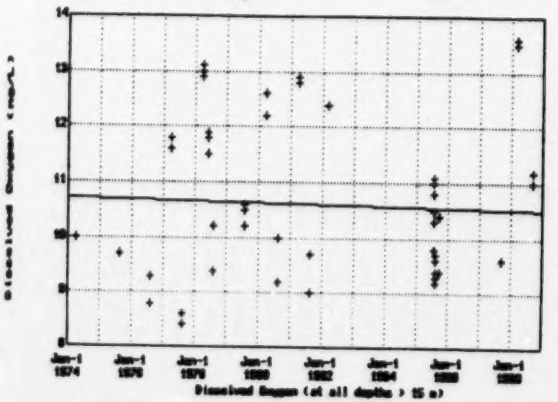
A.F. 2-14 Okanagan Lake - Vernon Arm



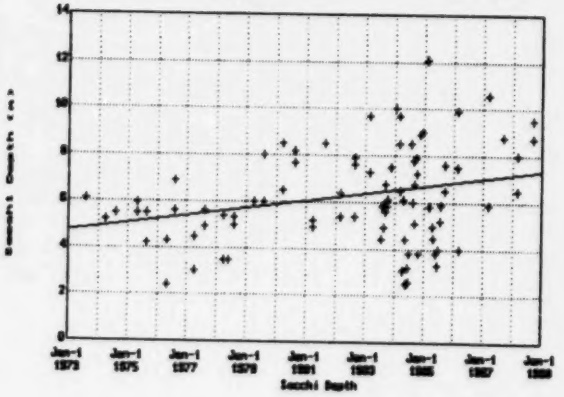
A.F. 2-15 Okanagan Lake - Vernon Arm



A.F. 2-16 Okanagan Lake - Vernon Arm

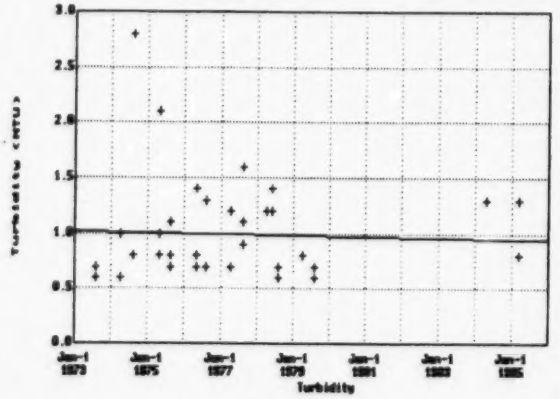


A.F. 2-17 Okanagan Lake - Vernon Arm

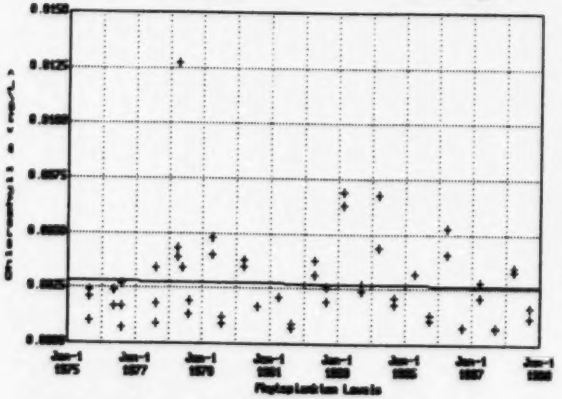


Appendix Figures (A.F.) 3-1 to 3-11. Okanagan Lake data for 2 sites in Armstrong Arm (0500460 and 0500239). Plotted are all data stored on SEAM OR EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

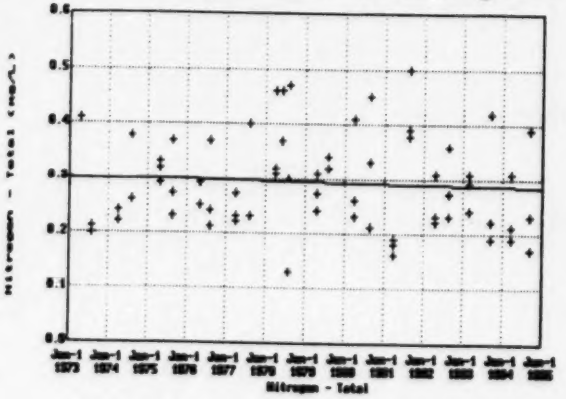
A.F. 2-18 Okanagan Lake - Vernon Arm



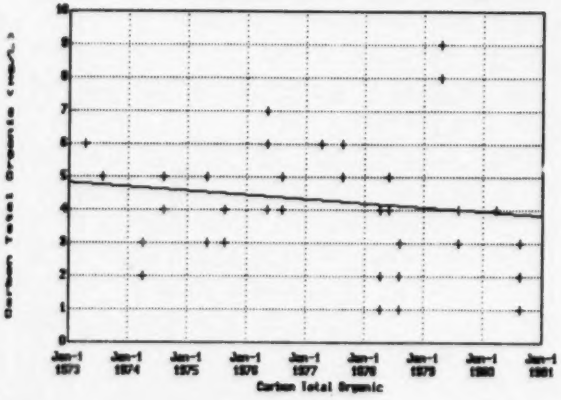
A.F. 3-2 Okanagan Lake - Armstrong Arm



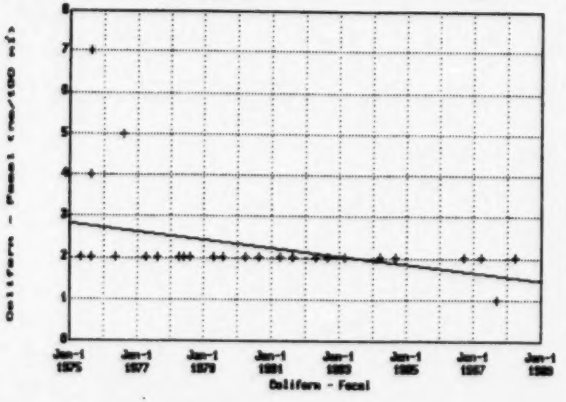
A.F. 3-4 Okanagan Lake - Armstrong Arm



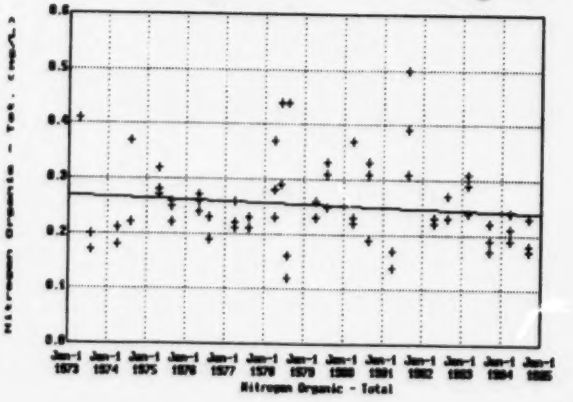
A.F. 3-1 Okanagan Lake - Armstrong Arm



A.F. 3-3 Okanagan Lake - Armstrong Arm

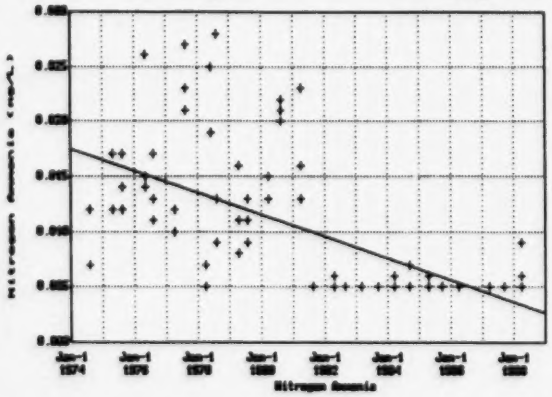


A.F. 3-5 Okanagan Lake - Armstrong Arm

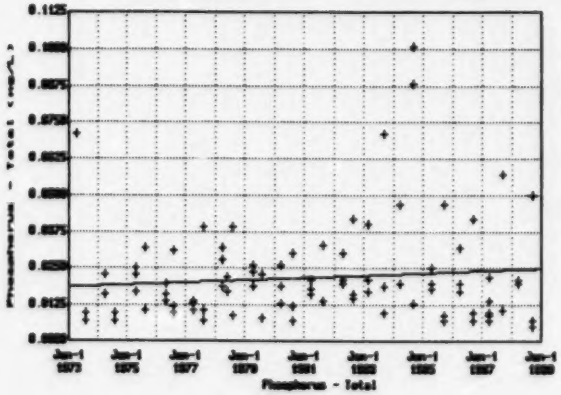


Appendix Figures (A.F.) 3-1 to 3-11. Okanagan Lake data for 2 sites in Armstrong Arm (0500460 and 0500239). Plotted are all data stored on SEAM OR EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

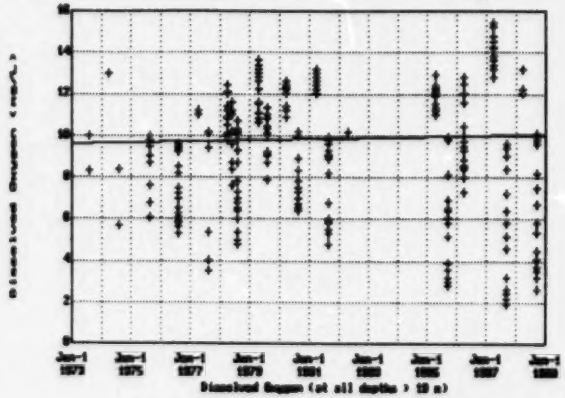
A.F. 3-6 Okanagan Lake - Armstrong Arm



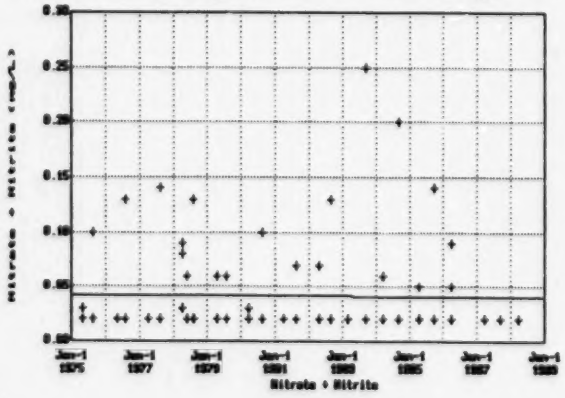
A.F. 3-8 Okanagan Lake - Armstrong Arm



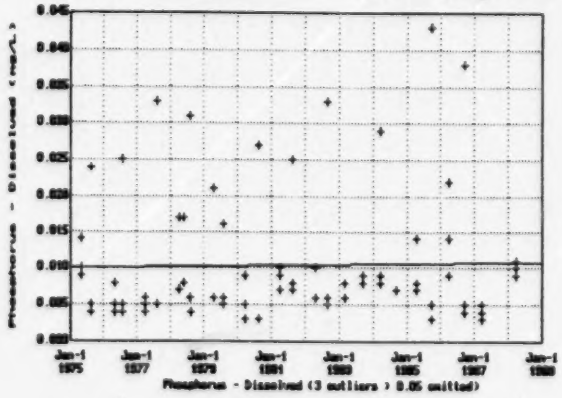
A.F. 3-10 Okanagan Lake - Armstrong Arm



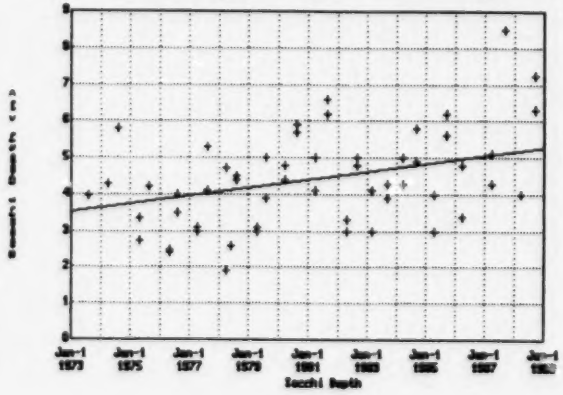
A.F. 3-7 Okanagan Lake - Armstrong Arm



A.F. 3-9 Okanagan Lake - Armstrong Arm

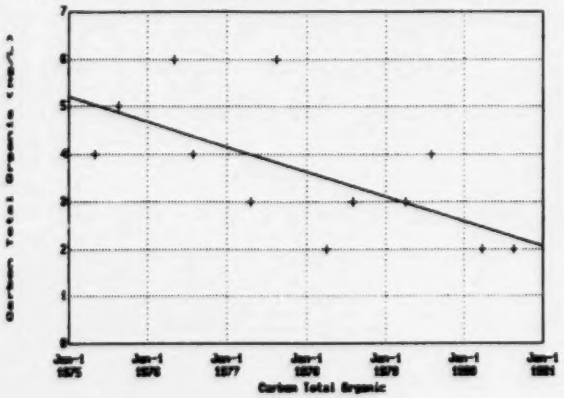


A.F. 3-11 Okanagan Lake - Armstrong Arm

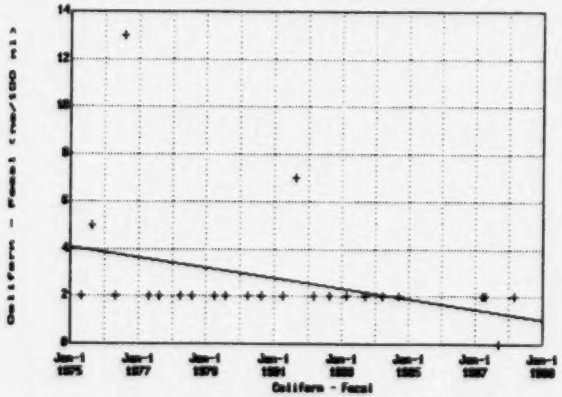


Appendix Figures (A.F.) 4-1 to 4-12. Okanagan Lake data for the site nearest Kelowna's outfall (0500242). The sampling site is about 100 m from the outfall pipe, although samples were collected farther offshore in deeper water in 1973 and 1974 so these data are not included. Plotted are data stored on SEAM or EQUIS regardless of season of year or depth of sample. The line is best fit by least squares regression.

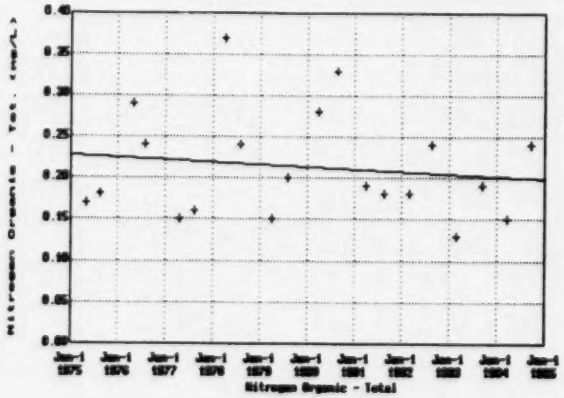
A.F. 4-1 Okanagan Lake–Kelowna Outfall



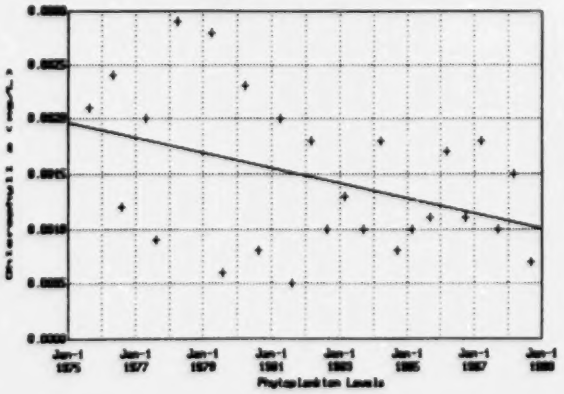
A.F. 4-3 Okanagan Lake–Kelowna Outfall



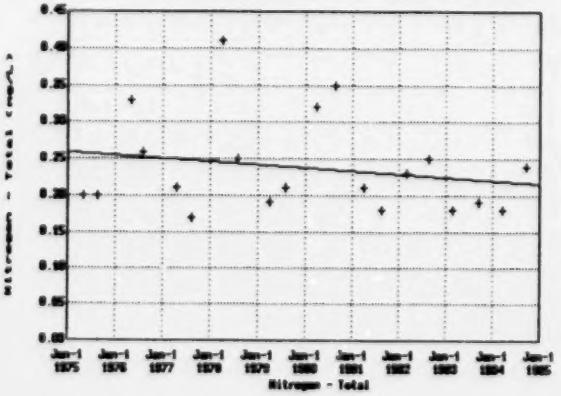
A.F. 4-5 Okanagan Lake–Kelowna Outfall



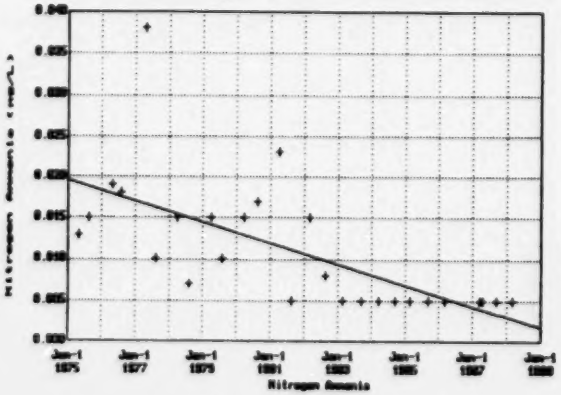
A.F. 4-2 Okanagan Lake–Kelowna Outfall



A.F. 4-4 Okanagan Lake–Kelowna Outfall

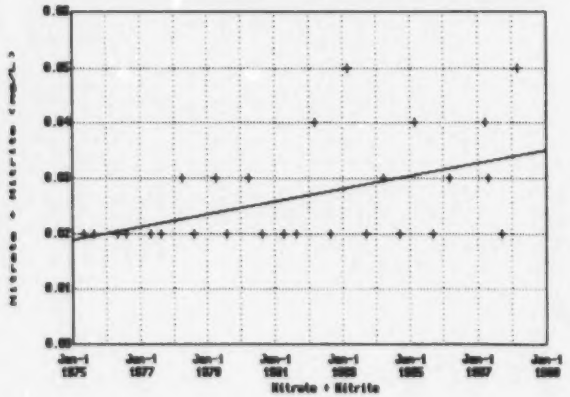


A.F. 4-6 Okanagan Lake–Kelowna Outfall

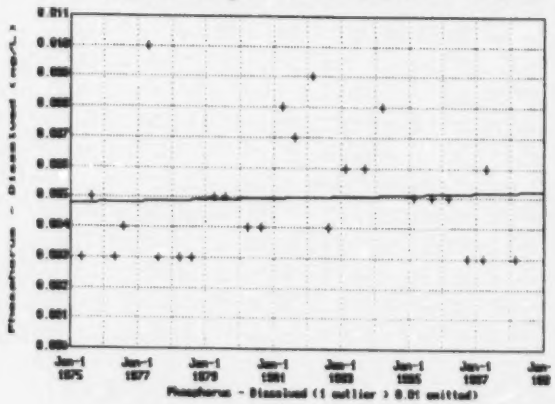


Appendix Figures (A.F.) 4-1 to 4-12. Okanagan Lake data for the site nearest Kelowna's outfall (0500242). The sampling site is about 100 m from the outfall pipe, although samples were collected farther offshore in deeper water in 1973 and 1974 so these data are not included. Plotted are data stored on SEAM or EQUIS regardless of season of year or depth of sample. The line is best fit by least squares regression.

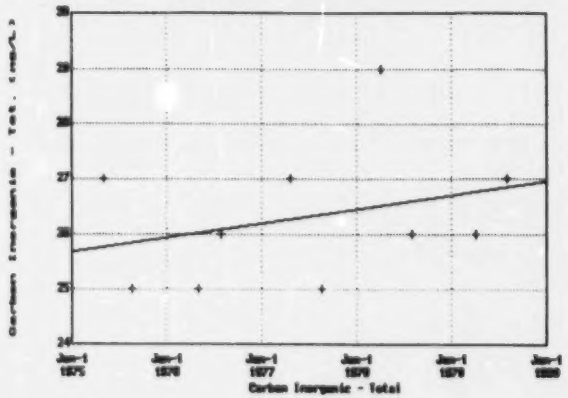
A.F. 4-7 Okanagan Lake–Kelowna Outfall



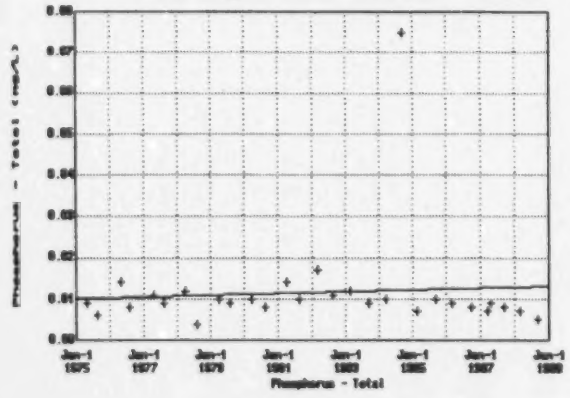
A.F. 4-9 Okanagan Lake–Kelowna Outfall



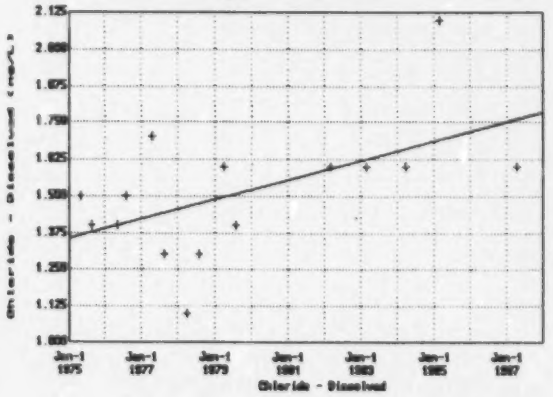
A.F. 4-11 Okanagan Lake–Kelowna Outfall



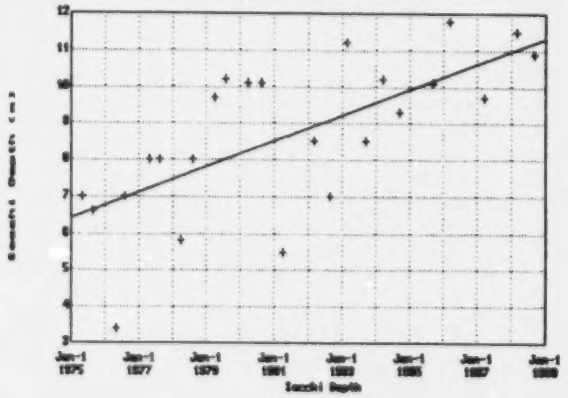
A.F. 4-8 Okanagan Lake–Kelowna Outfall



A.F. 4-10 Okanagan Lake–Kelowna Outfall

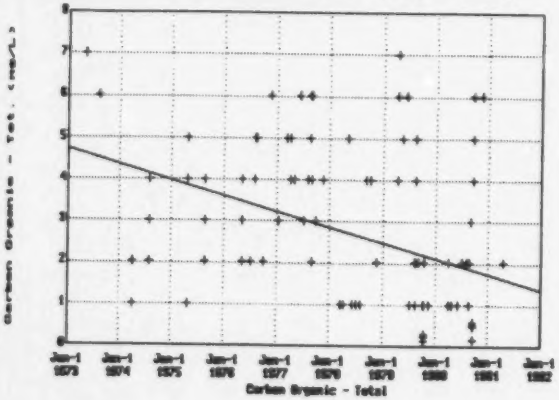


A.F. 4-12 Okanagan Lake–Kelowna Outfall

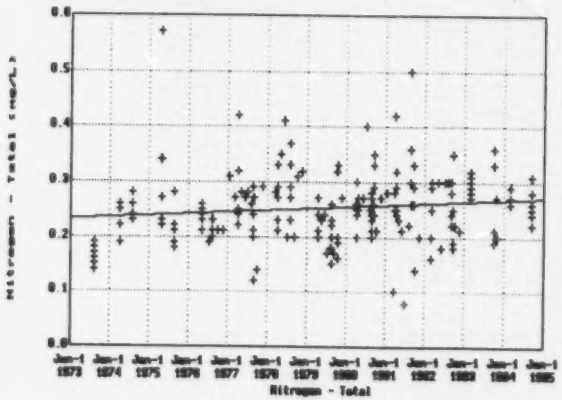


Appendix Figures (A.F.) 5-1 to 5-24. Kalamalka Lake data for 5 sites in Kalamalka Lake (0500246, 0500847 (or 0500247), 0500462, 0500580 (only data after 1985), 0500581). The latter two sites are shallow (10 m or 6 m respectively) whereas the rest of the sites are in deep water (30-160 m). Plotted are all data stored on SEAM regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

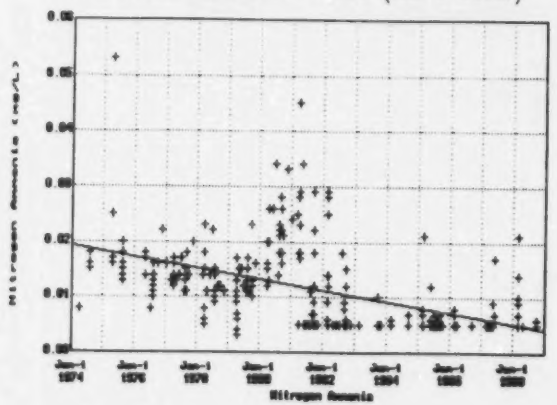
A.F. 5-1 Kalamalka Lake (All 5 Sites)



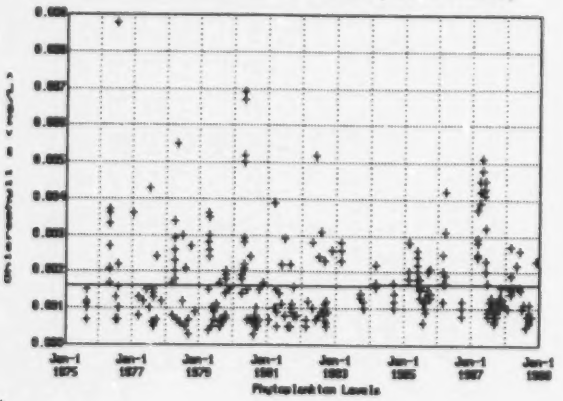
A.F. 5-3 Kalamalka Lake (All 5 Sites)



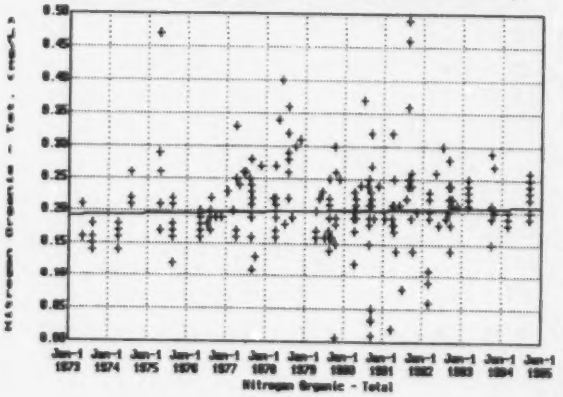
A.F. 5-5 Kalamalka Lake (All 5 Sites)



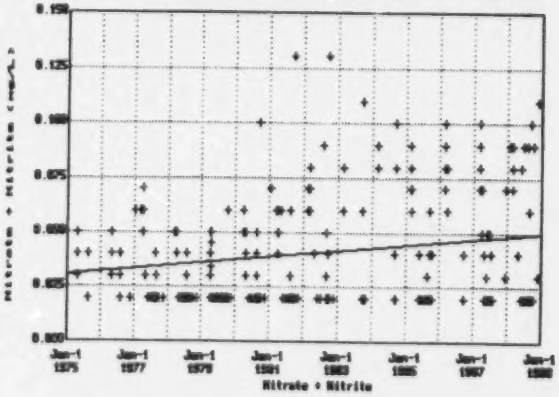
A.F. 5-2 Kalamalka Lake (All 5 Sites)



A.F. 5-4 Kalamalka Lake (All 5 Sites)

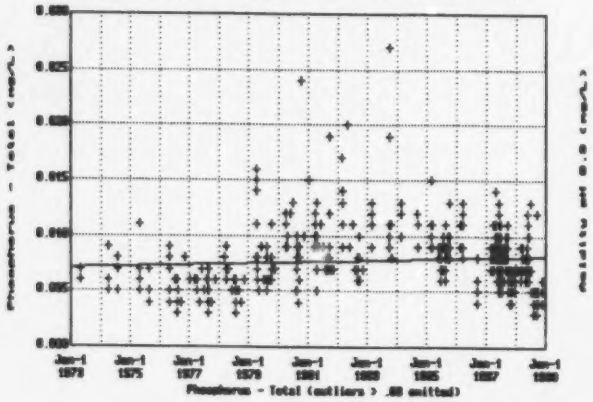


A.F. 5-6 Kalamalka Lake (All 5 Sites)

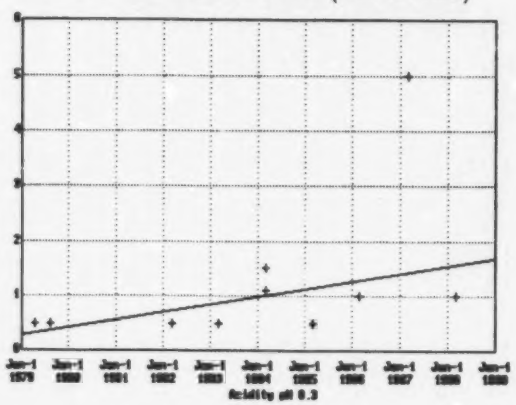


Appendix Figures (A.F.) 5-1 to 5-24. Kalamalka Lake data for 5 sites in Kalamalka Lake (0500246, 0500847 (or 0500247), 0500462, 0500580 (only data after 1985), 0500581). The latter two sites are shallow (10 m or 6 m respectively) whereas the rest of the sites are in deep water (30-160 m). Plotted are all data stored on SEAM regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

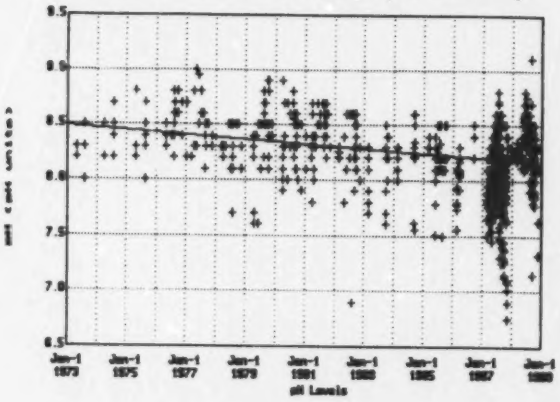
A.F. 5-7 Kalamalka Lake (All 5 Sites)



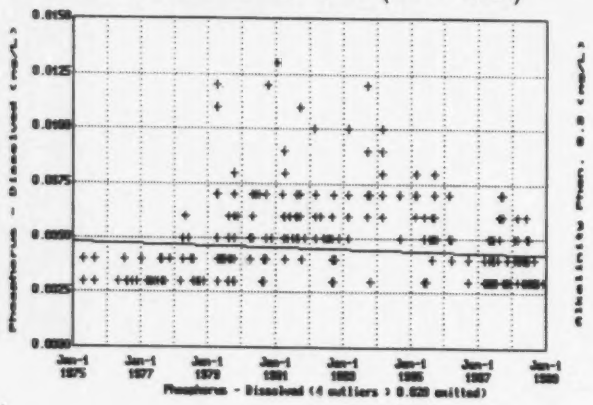
A.F. 5-9 Kalamalka Lake (All 5 Sites)



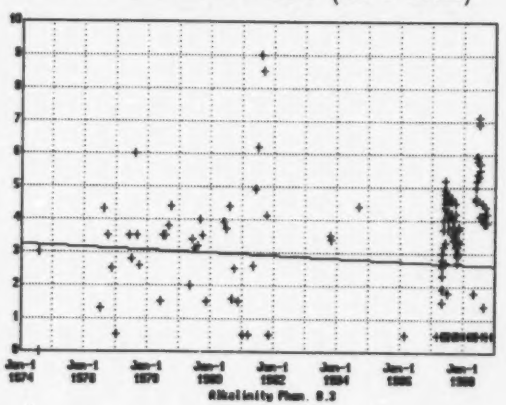
A.F. 5-11 Kalamalka Lake (All 5 Sites)



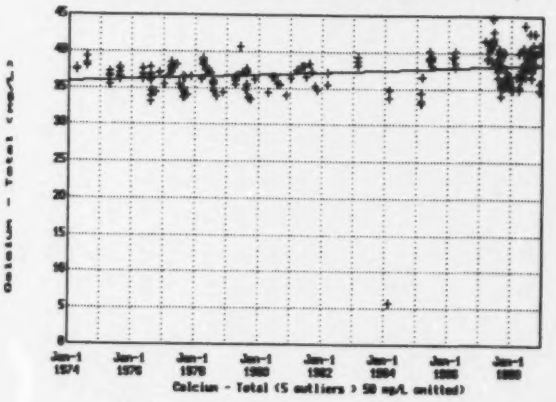
A.F. 5-8 Kalamalka Lake (All 5 Sites)



A.F. 5-10 Kalamalka Lake (All 5 Sites)

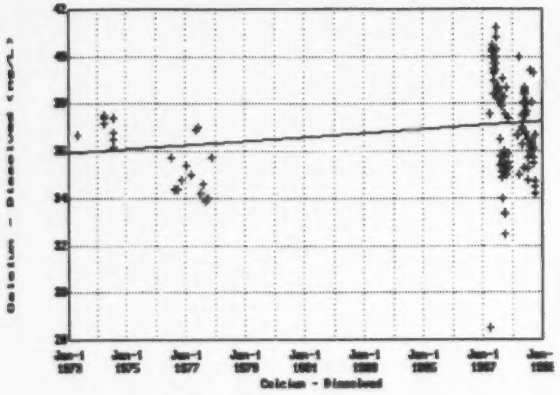


A.F. 5-12 Kalamalka Lake (All 5 Sites)

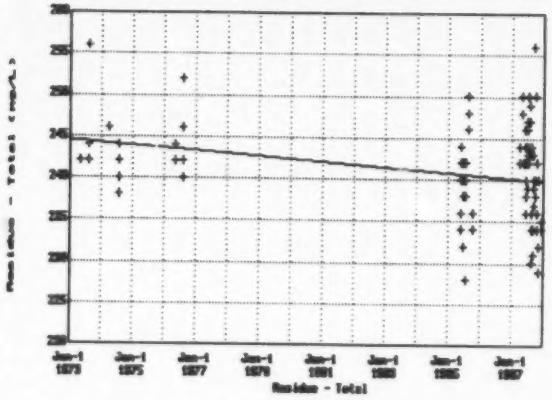


Appendix Figures (A.F.) 5-1 to 5-24. Kalamalka Lake data for 5 sites in Kalamalka Lake (0500246, 0500847 (or 0500247), 0500462, 0500580 (only data after 1985), 0500581). The latter two sites are shallow (10 m or 6 m respectively) whereas the rest of the sites are in deep water (30-160 m). Plotted are all data stored on SEAM regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

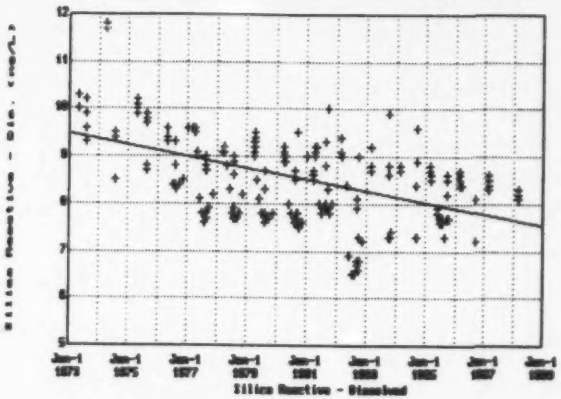
A.F. 5-13 Kalamalka Lake (All 5 Sites)



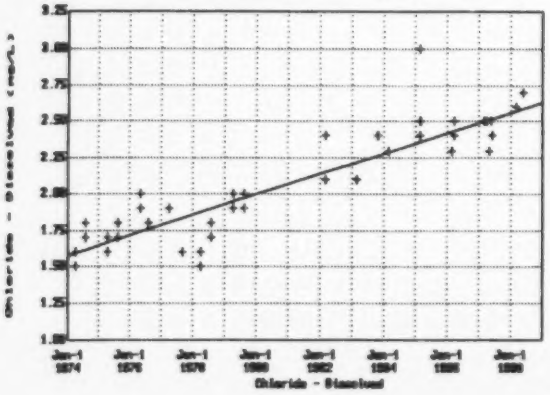
A.F. 5-15 Kalamalka Lake (All 5 Sites)



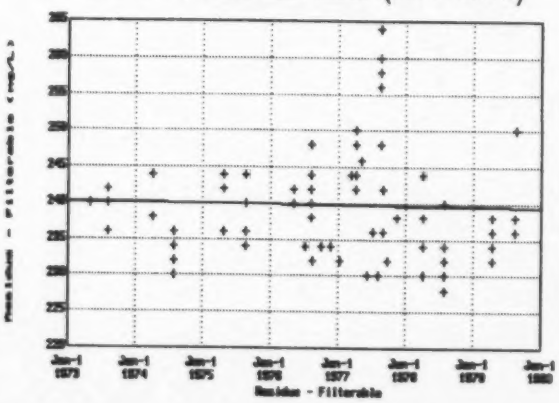
A.F. 5-17 Kalamalka Lake (All 5 Sites)



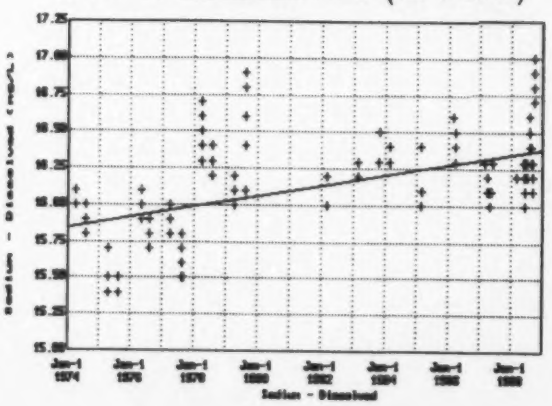
A.F. 5-14 Kalamalka Lake (All 5 Sites)



A.F. 5-16 Kalamalka Lake (All 5 Sites)

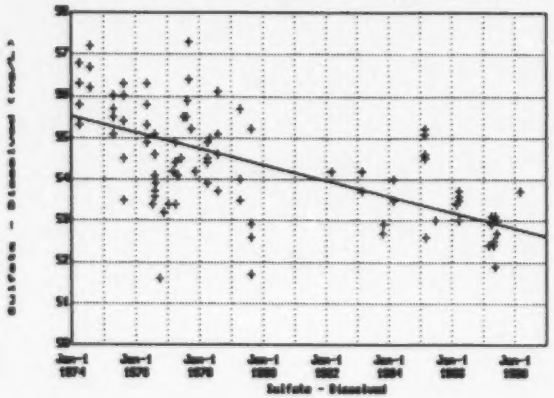


A.F. 5-18 Kalamalka Lake (All 5 Sites)

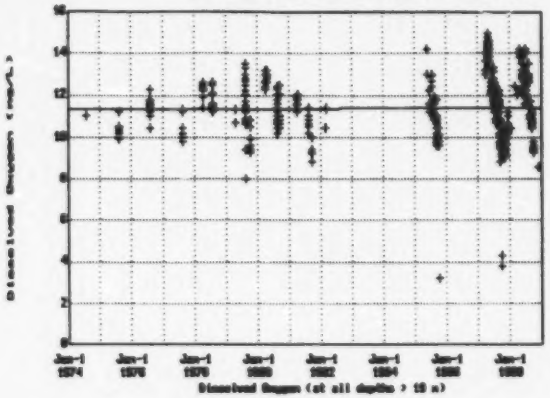


Appendix Figures (A.F.) 5-1 to 5-24. Kalamalka Lake data for 5 sites in Kalamalka Lake (0500246, 0500847 (or 0500247), 0500462, 0500580 (only data after 1985), 0500581). The latter two sites are shallow (10 m or 6 m respectively) whereas the rest of the sites are in deep water (30-160 m). Plotted are all data stored on SEAM regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

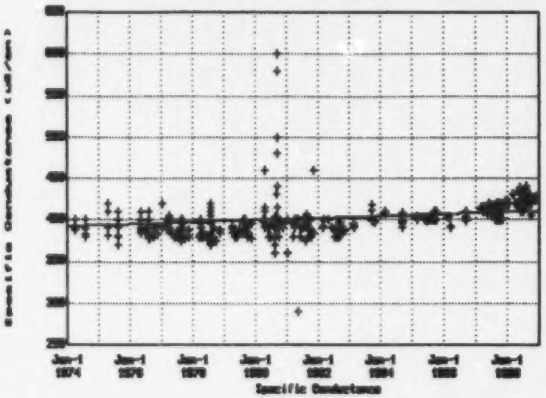
A.F. 5-19 Kalamalka Lake (All 5 Sites)



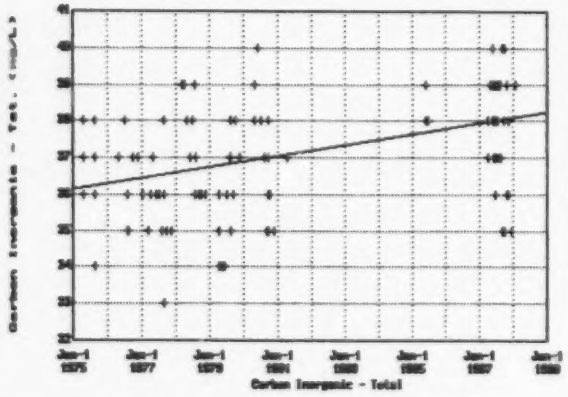
A.F. 5-21 Kalamalka Lake (All 5 Sites)



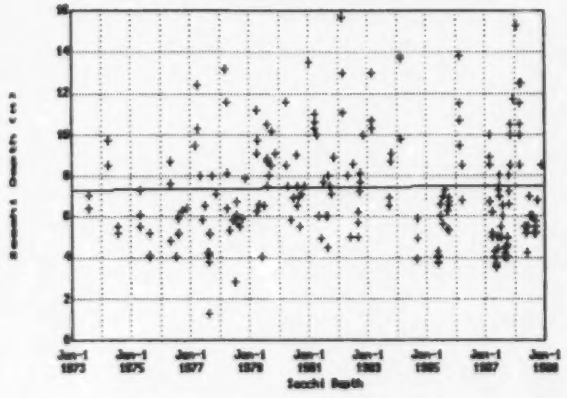
A.F. 5-23 Kalamalka Lake (All 5 Sites)



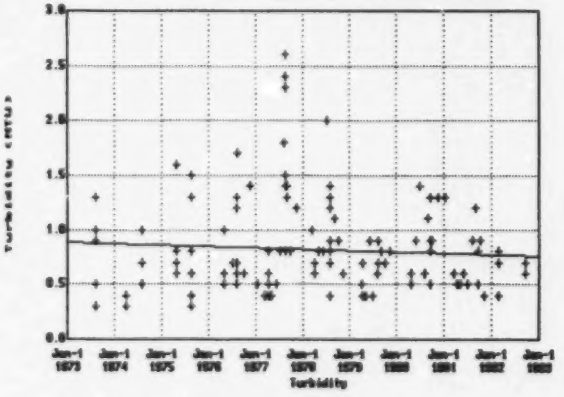
A.F. 5-20 Kalamalka Lake (All 5 Sites)



A.F. 5-22 Kalamalka Lake (All 5 Sites)

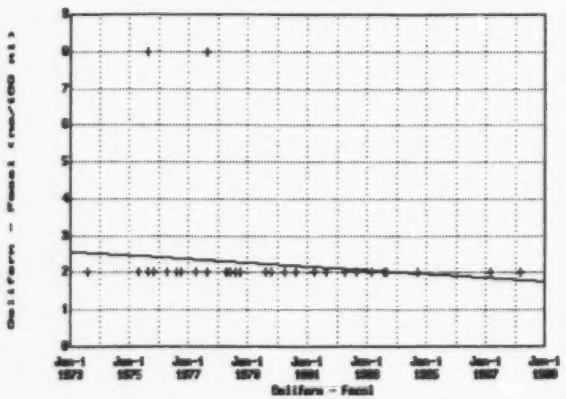


A.F. 5-24 Kalamalka Lake (All 5 Sites)

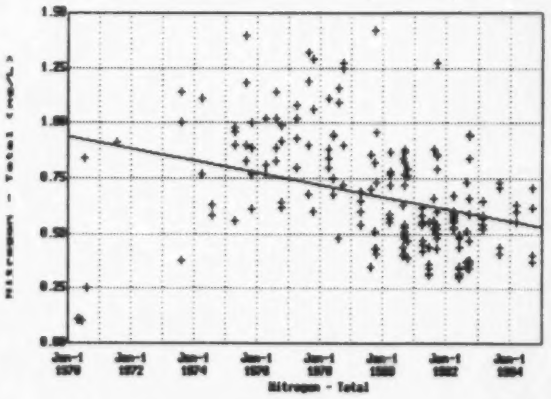


Appendix Figures (A.F.) 6-1 to 6-18. Wood Lake data for 2 sites (0500848 (or 0500245), 0500450) are about 33, 30, and 20 m, respectively. Plotted are all data stored on SEAM or EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

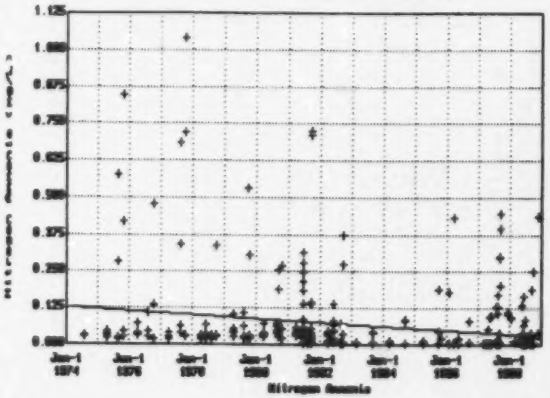
A.F. 6-1 Wood Lake (2 Sites)



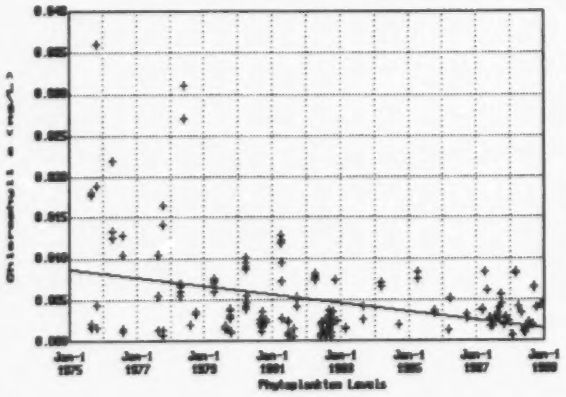
A.F. 6-3 Wood Lake (2 Sites)



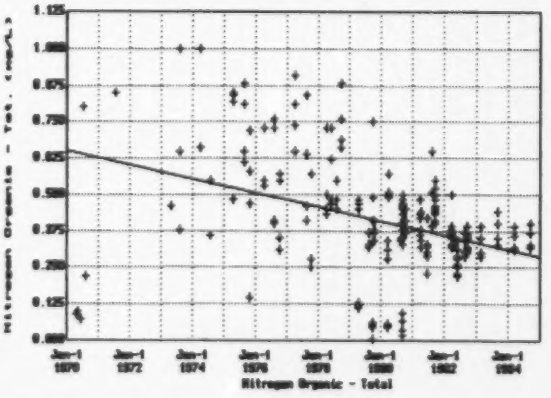
A.F. 6-5 Wood Lake (2 Sites)



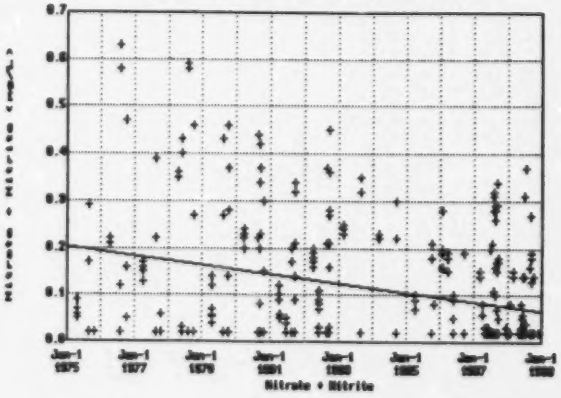
A.F. 6-2 Wood Lake (2 Sites)



A.F. 6-4 Wood Lake (2 Sites)

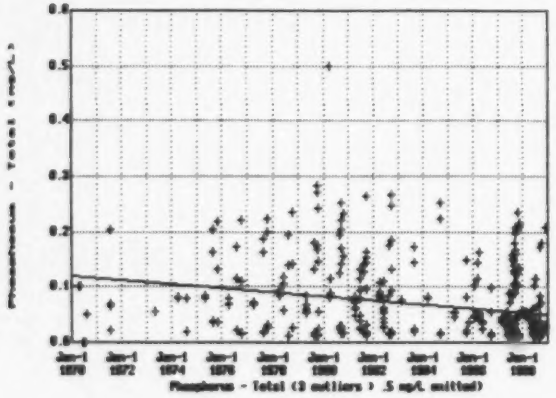


A.F. 6-6 Wood Lake (2 Sites)

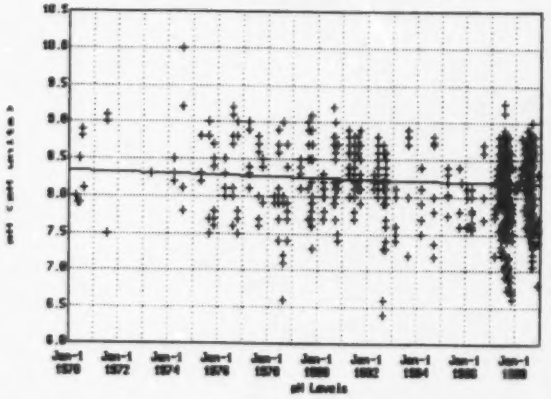


Appendix Figures (A.F.) 6-1 to 6-18. Wood Lake data for 2 sites (0500848 (or 0500245), 0500450) are about 33, 30, and 20 m, respectively. Plotted are all data stored on SEAM or EQUIS regardless of season of year or depth of sample (except for dissolved oxygen). The line is best fit by least squares regression.

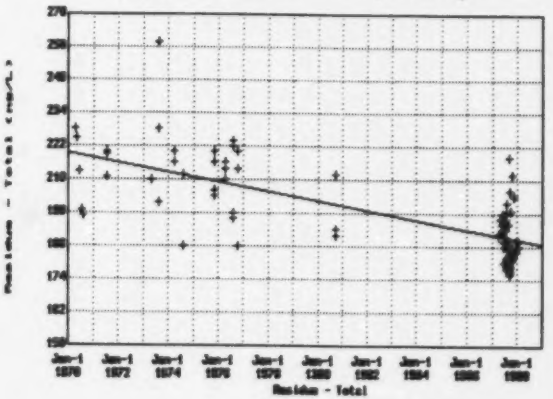
A.F. 6-7 Wood Lake (2 Sites)



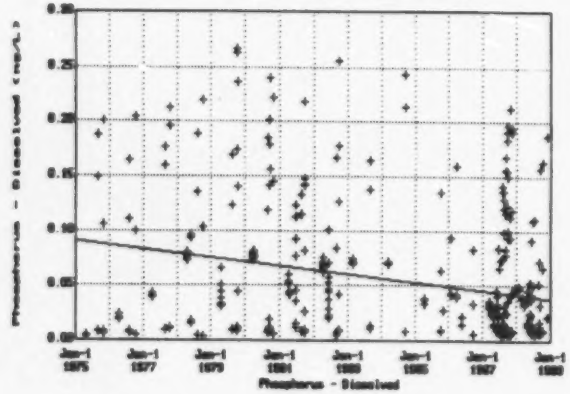
A.F. 6-9 Wood Lake (2 Sites)



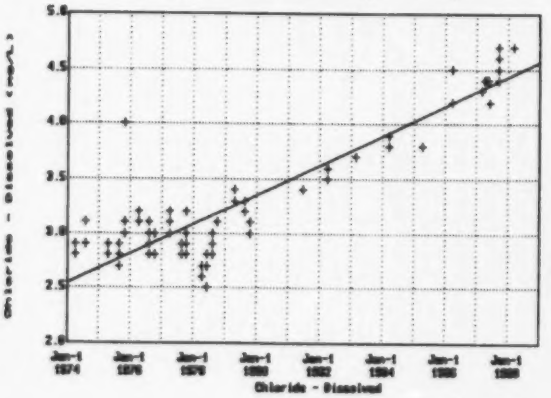
A.F. 6-11 Wood Lake (2 Sites)



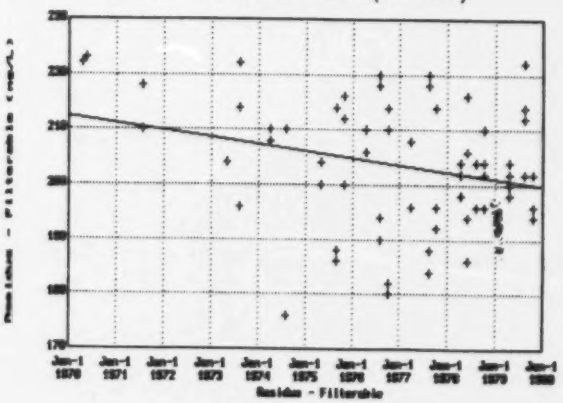
A.F. 6-8 Wood Lake (2 Sites)



A.F. 6-10 Wood Lake (2 Sites)



A.F. 6-12 Wood Lake (2 Sites)



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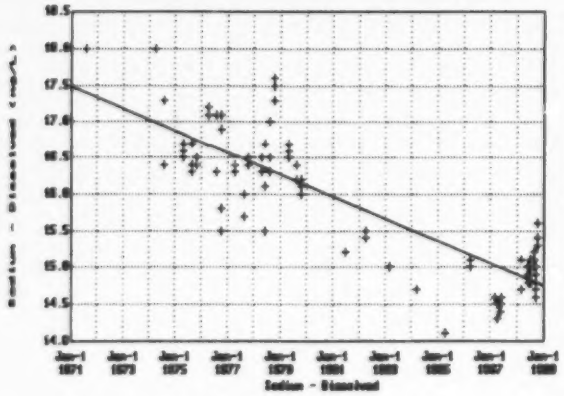
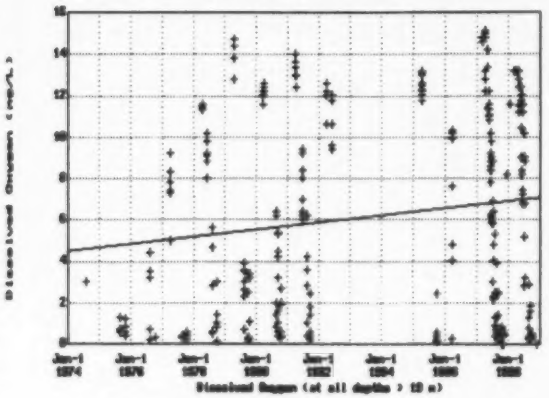
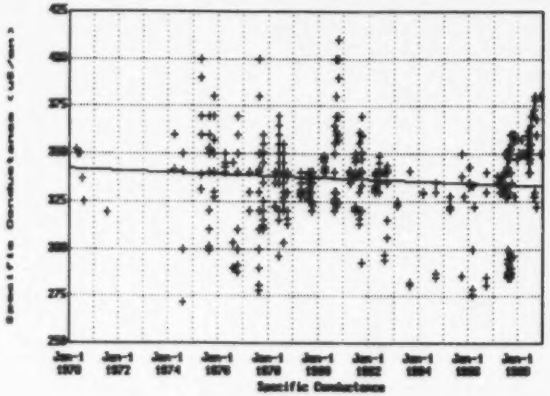
A.F. 6-13 Wood Lake (2 Sites)



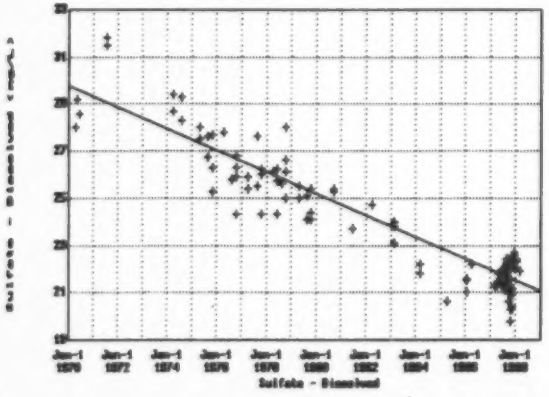
A.F. 6-15 Wood Lake (2 Sites)



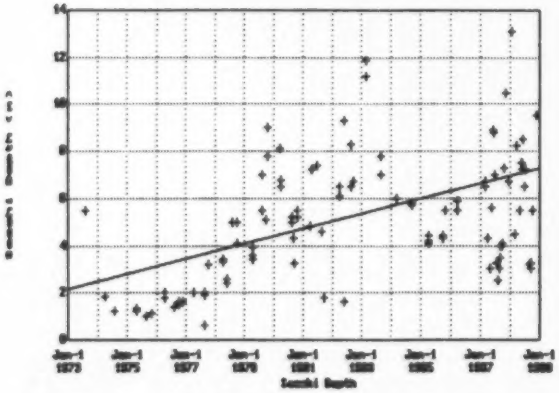
A.F. 6-17 Wood Lake (2 Sites)



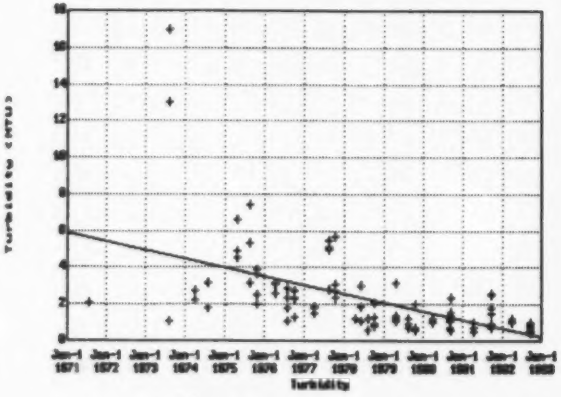
A.F. 6-14 Wood Lake (2 Sites)



A.F. 6-16 Wood Lake (2 Sites)



A.F. 6-18 Wood Lake (2 Sites)



MEANS	OKANAGAN LAKE SITES				KAL LAKE SITES		WOOD LAKE SITES
	Armstrong Arm 239	Vernon Arm 238	DNS Kelowna 236	Squally Point 729	South End 246	Main Basin 247,847	Main Basin 245,848
PARAMETER							
Biological:							
Carbon, total organic	4.39	3.97	1.90	1.53	3.62	2.64	5.57
Chlorophyll A (ug/L)	2.50	1.92	1.60	1.11	1.80	1.26	4.42
Coliform, fecal (MPN)	2.38	2.39	3.04	2.00	2.00	2.00	2.00
Macronutrients:							
Nitrogen, total	0.29	0.250	0.23	0.22	0.260	0.245	0.640
Nitrogen, organic	0.25	0.231	0.14	0.11	0.214	0.185	0.390
Nitrogen, ammonia	0.013	0.017	0.01	0.022	0.015	0.014	0.083
Nitrate and Nitrite	0.09	0.028	0.04	0.036	0.06	0.061	0.170
Phosphorus, total	0.024	0.013	0.009	0.010	0.009	0.006	0.066
Phosphorus, dissolved	0.015	0.008	0.006	0.008	0.006	0.005	0.054
Potassium	2.28	2.18	2.15	2.15	4.6	4.57	3.560
General ions:							
Acidity	-	1.38	2.22	1.83	1.1	2.13	3.50
Alkalinity, phen.	1.78	4.3	4.7	-	3.51	4.22	5.90
Alkalinity, total	113.	110.	108.	109.	147.	147.	138.
pH	8.16	8.28	8.00	7.97	8.19	8.60	8.22
Boron, dissolved	-	-	-	-	-	0.01	0.014
Calcium, total	34.82	32.7	32.8	33.52	37.	38.1	29.
Calcium, dissolved	34.98	32.9	32.6	-	37.	37.3	29.
Magnesium, total	9.12	8.61	8.49	8.68	17.6	18.8	15.5
Magnesium, dissolved	-	8.87	7.9	-	18.2	18.3	15.2
Hardness, dissolved	-	118.	114.	-	167.	167.	134.
Chloride	1.51	1.54	1.45	1.66	1.88	2.10	3.58
Fluoride	0.195	0.208	0.18	0.18	0.34	0.333	-
Residue, total	180.	169.	162.	-	243.	240.	196.
Residue, filterable	173.	163.	162.	-	240.	239.	195.
Silica	5.07	4.672	4.65	4.76	8.74	8.83	2.48
Sodium	9.7	9.44	9.49	9.77	16.02	16.2	15.54
Sulphate, dissolved	31.5	29.1	27.9	28.2	54.8	54.2	23.3
Physical							
Carbon, inorganic	28.4	26.8	27.4	27.2	37.	37.6	36.
Color (TAC)	1.	2.33	2.	2.	3.	1.5	4.
Oxygen (hypolimnion)	9.92	10.9	11.09	11.3	11.2	11.7	9.03
Secchi depth (m)	4.53	6.56	8.91	10.7	7.50	7.87	5.31
Specific conductance*	293.	277.	277.	270.	397.	407.	337.
Turbidity (NTU)	1.29	0.957	0.488	0.59	0.74	0.72	2.06

* uS/cm

Appendix Table 1. Mean values of water quality parameters for several sites in Okanagan, Kalamalka, and Wood Lakes. The data are all values stored on EQUIS or SEAM for the period of record which was different for different sites but ranged from 1970 to 1988. Except where specified, the units are mg/L.

MEANS	OKANAGAN LAKE SITES				KAL LAKE SITES		WOOD LAKE SITES
	Armstrong Arm 239	Vernon Arm 238	DNS Kelowna 236	Squally Point 729	South End 246	Main Basin 247,847	Main Basin 245,848
PARAMETER	E X C L U D I N G < a n d >						
Other metals:							
Aluminium	0.09	0.06	0.06	0.098	0.047	0.12	0.102
Arsenic	-	-	-	-	-	-	-
Cadmium	-	-	-	-	-	-	0.01
Chromium	0.01	-	-	-	0.02	0.012	0.012
Cobalt	0.17	-	-	-	-	-	-
Copper	0.006	0.003	0.004	0.002	0.012	0.015	0.012
Iron	0.095	0.07	0.04	0.028	-	0.049	0.043
Manganese	0.26	0.001	0.001	0.080	-	0.018	0.170
Molybdenum	0.009	0.003	0.007	0.007	0.009	0.012	0.013
Nickel	-	-	0.002	-	-	0.057	0.07
Lead	-	0.001	0.003	0.002	-	-	0.114
Vanadium	-	-	-	-	-	0.032	0.025
Zinc	0.01	0.02	0.008	0.02	0.015	0.020	0.015
	I N C L U D I N G < a n d >						
Other metals:							
Aluminium	0.09	0.04	0.03	0.059	0.033	0.11	0.090
Arsenic	0.25	0.20	0.13	0.12	0.25	0.259	0.175
Cadmium	0.004	0.005	0.006	0.008	0.006	0.010	0.010
Chromium	0.007	0.009	0.009	0.01	0.009	0.010	0.010
Cobalt	0.135	0.1	0.09	0.1	0.1	0.1	0.1
Copper	0.005	0.0072	0.008	0.006	0.008	0.010	0.010
Iron	0.095	0.06	0.02	0.023	0.046	0.042	0.039
Manganese	0.058	0.01	0.009	0.031	0.014	0.010	0.094
Molybdenum	0.009	0.007	0.009	0.008	0.010	0.015	0.012
Nickel	0.023	0.03	0.044	0.05	0.034	0.049	0.049
Lead	0.034	0.05	0.063	0.080	0.060	0.096	0.097
Vanadium	0.01	0.01	0.009	0.01	0.01	0.015	0.016
Zinc	0.009	0.01	0.010	0.011	0.009	0.013	0.012

Appendix Table 1 cont. Mean values of water quality parameters for several sites in Okanagan, Kalamalka, and Wood Lakes. The data are all values stored on EQUIS or SEAM for the period of record which was different for different sites but ranged from 1970 to 1988. Except where specified, the units are mg/L.

NUMBER OF VALUES	OKANAGAN LAKE SITES				KAL LAKE SITES		WOOD LAKE SITES
	Armstrong Arm 239	Vernon Arm 238	DNS Kelowna 236	Squally Point 729	South End 246	Main Basin 247,847	Main Basin 245,848
PARAMETER							
Biological:							
Carbon, total organic	31	33	121	80	26	48	81
Chlorophyll A	32	30	118	111	42	84	128
Coliform, fecal	21	23	23	4	22	18	29
Macronutrients:							
Nitrogen, total	48	49	74	38	47	65	145
Nitrogen, organic	48	49	117	72	48	70	162
Nitrogen, ammonia	36	33	104	66	-	74	244
Nitrate and Nitrite	23	19	103	80	43	78	173
Phosphorus, total	68	68	141	105	95	187	384
Phosphorus, dissolved	56	51	134	99	67	164	364
Potassium	20	23	22	10	22	32	51
General ions:							
Acidity	0	6	6	4	1	4	8
Alkalinity, phen.	4	4	2	0	12	75	70
Alkalinity, total	10	15	12	8	42	133	175
pH	121	112	194	115	214	454	640
Boron, dissolved	-	0	-	-	0	3	19
Calcium, total	28	33	31	10	31	135	237
Calcium, dissolved	5	6	1	-	5	110	92
Magnesium, total	27	33	31	10	32	135	243
Magnesium, dissolved	5	0	1	-	5	110	86
Hardness, dissolved	-	5	1	-	5	5	8
Chloride	29	33	30	8	28	38	68
Fluoride	4	4	1	1	4	4	
Residue, total	12	11	8	-	17	37	83
Residue, filterable	28	29	26	-	28	84	101
Silica	60	58	85	46	63	76	142
Sodium	29	33	30	8	30	72	105
Sulphate, dissolved	29	34	30	8	30	36	157
Physical							
Carbon, inorganic	22	22	34	12	20	78	92
Color	1	3	4	2	1	2	18
Oxygen (hypolimnion)	335	176	425	168	351	657	872
Secchi depth	54	49	69	33	71	93	127
Specific conductance	327	246	447	111	344	472	764
Turbidity	28	28	49	24	27	49	85

Appendix Table 2. Number of samples for each water quality parameter in Table 1 for several sites in Okanagan, Kalamalka and Wood Lakes. The data are all values stored on EQUIS or SEAM for the period of record which was different for different sites but ranged from 1970 to 1988.

NUMBER OF VALUES	OKANAGAN LAKE SITES				KAL LAKE SITES		WOOD LAKE SITES
	Armstrong Arm 239	Vernon Arm 238	DNS Kelowna 236	Squally Point 729	South End 246	Main Basin 247,847	Main Basin 245,848
PARAMETER	E X C L U D I N G < a n d >						
Other metals:							
Aluminium	2	3	2	4	4	32	40
Arsenic	0	0	0	0	0	0	2
Cadmium	0	0	8	0	0	0	2
Chromium	1	1	8	0	1	10	17
Cobalt	1	0	7	0	0	0	0
Copper	3	4	9	5	3	16	39
Iron	6	6	3	7	1	89	176
Manganese	1	1	1	3	0	4	108
Molybdenum	6	5	4	8	8	78	89
Nickel	0	0	1	0	0	3	4
Lead	0	1	2	1	0	0	4
Vanadium	0	0	0	0	0	26	77
Zinc	2	2	1	1	2	30	71
	I N C L U D I N G < a n d >						
Other metals:							
Aluminium	2	5	6	8	7	35	64
Arsenic	2	5	8	13	7	20	21
Cadmium	6	10	0	10	11	117	204
Chromium	6	10	0	10	11	117	201
Cobalt	2	6	0	9	7	112	195
Copper	6	10	4	13	11	117	204
Iron	6	10	9	10	11	117	208
Manganese	6	10	8	10	11	117	204
Molybdenum	6	10	8	13	11	117	200
Nickel	6	10	8	10	11	117	200
Lead	6	10	8	10	11	117	203
Vanadium	2	6	7	9	7	112	195
Zinc	6	10	8	10	11	117	204

Appendix Table 2 cont. Number of samples for each water quality parameter in Table 1 for several sites in Okanagan, Kalamalka and Wood Lakes. The data are all values stored on EQUIS or SEAM for the period of record which was different for different sites but ranged from 1970 to 1988.

STANDARD ERROR OF MEAN	OKANAGAN LAKE SITES				KAL LAKE SITES			WOOD LAKE SITES	
	Armstrong Arm 239	Vernon Arm 238	DNS Kelowna 236	Squally Point 729	South End 246	Main Basin 247	847	Main Basin 245	848
PARAMETER									
Biological:									
Carbon, total organic	0.306	0.2403	0.1827	0.2206	0.4117	0.2954	-	0.4275	-
Chlorophyll A	0.0537	0.2880	0.1248	0.0133	0.4081	0.219	-	0.5060	-
Coliform, fecal	0.271	1.3730	0.9164	-	-	-	0	0	0
Macronutrients:									
Nitrogen, total	0.013	0.0144	0.0117	0.0082	0.0082	0.0069	-	0.0225	-
Nitrogen, organic	0.011	0.0137	0.0108	0.0106	0.0070	-	0.0073	-	0.0148
Nitrogen, ammonia	0.001	0.0016	0.0008	0.0151	0.0011	0.0008	-	-	0.0091
Nitrate and Nitrite	0.012	0.0026	0.0020	0.0026	0.0030	0.0038	-	-	0.0111
Phosphorus, total	0.002	0.0018	0.0008	0.0016	0.0012	0.0004	-	-	0.0033
Phosphorus, dissolved	0.002	0.0022	0.0008	0.0017	0.0016	0.0003	-	-	0.0033
Potassium	0.016	0.0140	0.0157	0.0224	0.0263	-	0.0137	-	0.0341
General ions:									
Acidity	-	0.1815	0.5180	0.2496	-	-	0.9656	-	1.1641
Alkalinity, phen.	0.606	1.6036	-	-	0.2008	-	0.1323	-	2.2886
Alkalinity, total	1.126	0.2702	0.3580	0.375	0.3963	-	0.2395	-	0.5280
pH	0.036	0.0284	0.0511	0.0595	0.0241	-	0.0162	-	0.0253
Boron, dissolved	-	-	-	-	-	-	-	-	-
Calcium, total	0.288	0.2741	0.2462	0.3777	0.2722	-	0.2146	-	0.2536
Calcium, dissolved	0.532	0.2011	-	-	0.1985	-	0.2101	-	0.3799
Magnesium, total	0.109	0.1030	0.0907	0.1658	0.1245	-	0.0788	-	0.0725
Magnesium, dissolved	0.384	0.2050	-	-	0.3209	-	0.0850	-	0.0978
Hardness, dissolved	-	0.9487	-	-	1.1662	1.2884	-	3.7489	-
Chloride	0.031	0.0218	0.0392	0.0420	0.0552	-	0.0404	0.0508	-
Fluoride	0.006	0.0144	-	-	0.0063	0.0111	-	0.0135	-
Residue, total	7.326	3.0184	1.2211	-	0.9065	-	0.7879	-	1.1553
Residue, filterable	1.350	0.705	0.7524	-	1.4081	-	0.7708	-	1.1242
Silica	0.148	0.6207	0.0403	0.0573	0.1173	0.1307	-	0.1377	-
Sodium	0.068	0.2320	0.0609	0.0453	0.0659	-	0.0300	-	0.0358
Sulphate, dissolved	0.263	0.2030	0.1297	0.2228	0.2364	-	0.2018	-	0.0567
Physical									
Carbon, inorganic	0.449	0.3081	0.2313	0.2072	0.3325	-	0.1874	0.5923	0.4670
Color	-	0.8819	0.4082	-	-	-	-	-	0.9027
Oxygen (hypolimnion)	0.161	0.126	0.0655	0.1139	0.0785	-	0.0748	0.1972	0.2244
Secchi depth	0.166	0.2582	0.2312	0.3635	0.3111	0.4283	-	0.2847	0.3790
Specific conductance	0.845	0.695	0.7754	1.0006	0.6863	-	0.7334	0.8725	-
Turbidity	0.057	0.0949	0.0219	0.0876	0.0861	0.0521	-	0.2670	-

Appendix Table 3. Standard errors of the mean for each water quality parameter in Table 1 for several sites in Okanagan, Kalamalka and Wood Lakes. The data are all values stored on EQUIS or SEAM for the period of record which was different for different sites but ranged from 1970 to 1988.

STANDARD ERROR OF MEAN	OKANAGAN LAKE SITES				KAL LAKE SITES			WOOD LAKE SITES	
	Armstrong Arm 239	Vernon Arm 238	DNS Kelowna 236	Squally Point 729	South End 246	Main Basin 247	847	Main Basin 245	848
PARAMETER									
	E X C L U D I N G < a n d >								
Other metals:									
Aluminium	-	0.01	-	0.0509	0.0176	-	0.0058	0.0033	-
Arsenic	-	-	-	-	-	-	-	-	-
Cadmium	-	-	-	-	-	-	-	-	-
Chromium	-	-	-	-	-	-	0.0015	-	0.002
Cobalt	-	-	-	-	-	-	-	-	-
Copper	0.002	0.0013	0.0023	0.0003	-	-	0.0045	0.0020	-
Iron	0.025	0.0297	0.0120	0.0046	-	-	0.0072	-	0.0033
Manganese	-	-	-	0.0797	-	-	0.0025	0.0248	-
Molybdenum	0.003	0.0003	0.0043	0.0028	0.0018	-	0.0008	-	0.0006
Nickel	-	-	-	-	-	-	-	-	-
Lead	-	-	-	-	-	-	-	-	-
Vanadium	-	-	-	-	-	-	0.0019	-	0.0090
Zinc	-	-	-	-	-	-	0.0036	-	0.0014
	I N C L U D I N G < a n d >								
Other metals:									
Aluminium	-	0.0112	0.0114	0.0277	0.0099	-	0.0071	0.0084	-
Arsenic	-	0.0498	0.0451	0.0350	-	-	0.0157	0.0498	-
Cadmium	0.002	0.0016	0.0017	0.0013	0.0015	-	0.0008	-	0.0004
Chromium	0.001	0.0015	0.0006	-	0.0015	-	0.0001	-	0.0002
Cobalt	-	-	0.0141	-	0	-	0	-	0
Copper	0.002	0.0011	0.0013	0.0012	0.0019	-	0.0006	-	0.0004
Iron	0.025	0.0197	0.0063	0.0042	0.0147	-	0.0058	-	0.0029
Manganese	0.040	0.0021	0.0011	0.0232	0.0016	-	0.0002	-	0.0142
Molybdenum	0.003	0.0011	0.0021	0.0017	0.0014	-	0.0006	-	0.0003
Nickel	0.008	0.0065	0.006	-	0.0065	-	0.0005	-	0.0003
Lead	0.021	0.0165	0.0179	0.0131	0.0162	-	0.0009	-	0.0007
Vanadium	-	-	0.0011	-	0	-	0.0010	-	0.0006
Zinc	0.002	0.0022	0.0002	0.001	0.001	-	0.0010	-	0.0005

Appendix Table 3 cont. Standard errors of the mean for each water quality parameter in Table 1 for several sites in Okanagan, Kalamalka and Wood Lakes. The data are all values stored on EQUIS or SEAM for the period of record which was different for different sites but ranged from 1970 to 1988.